Sellafield Ltd

Particles in the Environment

Annual Report for 2016/17 and Forward Programme

June 2017

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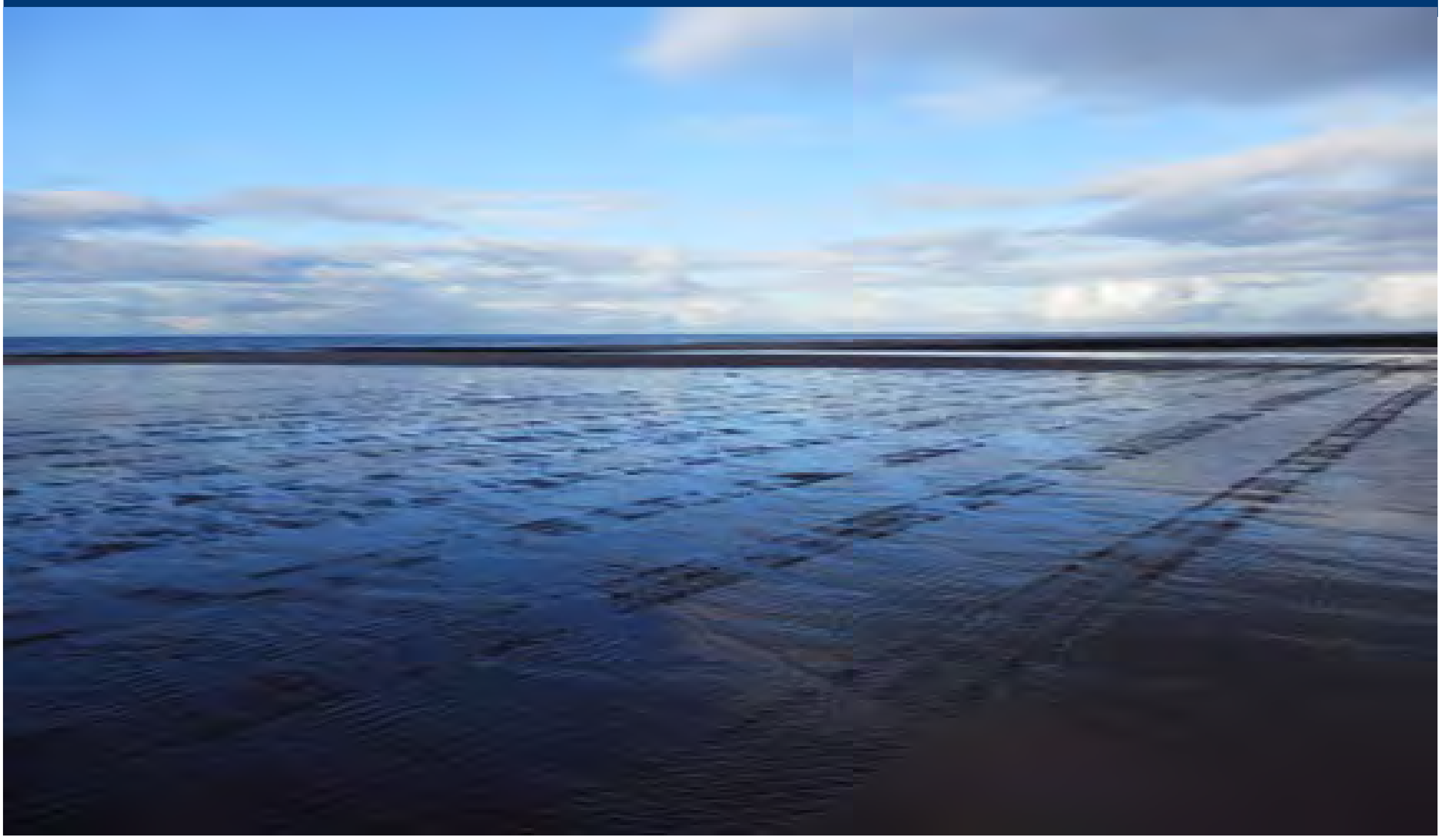

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Particles in the Environment Annual Report 2016/17

Executive Summary

This report details the progress that has been made during the 2016/17 financial year on the Particles in the Environment work programme. It also sets out the forward programme of work, with objectives, as previously submitted to the Environment Agency and agreed in February 2017 through the Sellafield Particles Working Group.

A total of 166.7 ha of beach were monitored in 2016/17, exceeding the Environment Agency's specification of 160 ha. The surveying identified 254 radioactive items, of which 206 were classified as particles (less than 2 mm in size) and 48 as objects (larger than 2 mm in size). A total of 180 of the finds were designated alpha rich, with higher ^{241}Am activity than ^{137}Cs activity and 74 were designated beta rich where ^{137}Cs was the major radionuclide. All of the objects were designated beta rich. As observed previously, the majority of finds were recovered from Sellafield beach (82%). The numbers of finds in all categories were typical of those found in recent years.

Further analyses of selected finds during 2016/17 have been performed using various radiometric and petrological techniques. The highest total beta and ^{137}Cs activities on beach finds sent for analysis was 1.35E+05 and 1.16E+05 Bq respectively. These activities were associated with a 'Rock fragment' object from the Sellafield beach. The highest ^{90}Sr activity (1.03E+04 Bq) was associated with a 'Graphite' particle from Sellafield beach. This 'Graphite' particle also contained 1.63E+04 Bq of ^{137}Cs. An analysis of the relationship between ^{90}Sr and ^{137}Cs activities of particles analysed since 2011 showed that the ^{137}Cs activity was highly variable for ^{90}Sr activities up to 2-3 kBq. However, a strong linear trend was shown between ^{90}Sr and ^{137}Cs for activities greater than 3 kBq of ^{90}Sr.

An update on the assessment of the Best Available Techniques (BAT) for particles monitoring considered the recent review of a coastal geomorphology and sediment transport and the trials of photographic analysis of the beach using an unmanned aerial vehicle. This work supported the conclusions of the 2014 BAT assessment.

The types of material being recovered during 2016/17 remained consistent with those retrieved since commencement of the monitoring programme. The distribution of ^{137}Cs and ^{241}Am activities of current particles remain within observed ranges of all particles to date, providing reassurance that they are part of the same general population. This provides further evidence that the conclusion of the Public Health England risk assessment in 2011 remains valid, and are as follows.

"The conclusion, based on the currently available information, is that the overall health risks to beach users are very low and significantly lower than other risks that people accept when using the beaches." (Brown & Etherington, 2011).

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1 Introduction

The overall objective of the Sellafield Ltd Particles in the Environment programme is to understand the nature of radioactive particles and objects being detected on local beaches and to quantify the potential health risk they pose. This report details the progress that has been made in 2016/17 on the Particles in the Environment work streams and sets out the programme of work for the 2017 calendar year.

In June 2011, the most comprehensive report to date on Particles in the Environment was produced and submitted to the Environment Agency (EA) (Sellafield Ltd, 2011). Readers are directed to this, and subsequent reports, as a source of further information. Extensive information is available via the sellafieldsites.com website at the following address:

http://sustainability.sellafieldsites.com/environment/environment-page/particles-in-the-environment/

In summary, this report includes the following:

Section 2 provides information on the particle detection systems used for beach monitoring.

Section 3 details the progress made in 2016/17 against the beach monitoring programme.

Section 4 provides the analysis of the monitoring and find data gathered up to the end of the 2016/17 financial year.

Section 5 provides an update on work completed on developing an updated Best Available Techniques (BAT) case for work on particles detection in the environment.

Section 6 explains how the regulators and stakeholders are being engaged by Sellafield Ltd and the framework for continued interactions.

Section 7 provides a brief update on the assessment of health risk posed by beach finds, being led by Public Health England (PHE) Centre for Radiation, Chemical and Environmental Hazards (formally Health Protection Agency, HPA CRCE) under contract to the EA.

Section 8 outlines the work programme and objectives for 2017.

2 Detection Systems

2.1 The Synergy 2 Detection System

The Groundhog Synergy system was a development of the Groundhog Evolution system that has been used for particle detection on beaches at Dounreay. The Evolution2 system was used at Sellafield up to August 2009 and was primarily designed to detect particles containing ^{137}Cs.

The Synergy system was used between August 2009 and May 2014 and was developed to improve detection of particles containing ^{241}Am, principally by improving radiation transmission through the detector cases and by the introduction of low-energy radiation detectors (Field Instrument for the Detection of Low Energy Radiation, FIDLER, detectors). The Synergy system used five 76 x 400 mm sodium iodide (NaI) detectors which provided a continuous monitoring swathe of two metres. These detectors were individually mounted in 2 mm thick carbon fibre cases to improve the transmission of radiation, particularly the low energy gamma radiation from ^{241}Am. The five detectors were mounted in a large carbon fibre box. The system also included eight FIDLER detectors that are optimal for the detection of low energy gamma radiation from ^{241}Am. Each detector was mounted in a carbon fibre case which had a 0.4 mm thick detection window. The eight FIDLER detectors were also mounted in the carbon fibre box and used a further 0.4 mm carbon fibre protective window.

In May 2014 Nuvia Ltd commissioned the Groundhog Synergy 2 system. The Synergy 2 system was designed to further improve detection of ^{241}Am and ^{90}Sr/^{90}Y. The detection system of Synergy 2 is physically the same as Synergy (Figure 1), except that it includes a thinner window of carbon fibre below the large volume NaI detectors to improve the transmission of beta radiation. The Synergy 2 system also includes additional specific strontium / americium alarms both for the sodium iodide and FIDLER detectors, measuring decay energies in a detection window centred on 80 keV. Based on information provided by Nuvia Ltd, this revised alarm was predicted to reduce the limits of detection of ^{241}Am with some additional benefit to the detection of ^{90}Sr (Davies, 2014). However, whilst it was anticipated that the performance for ^{90}Sr detection would also be improved, it was less clear what might be achieved because detection of both beta particles and Bremsstrahlung radiation was possible.

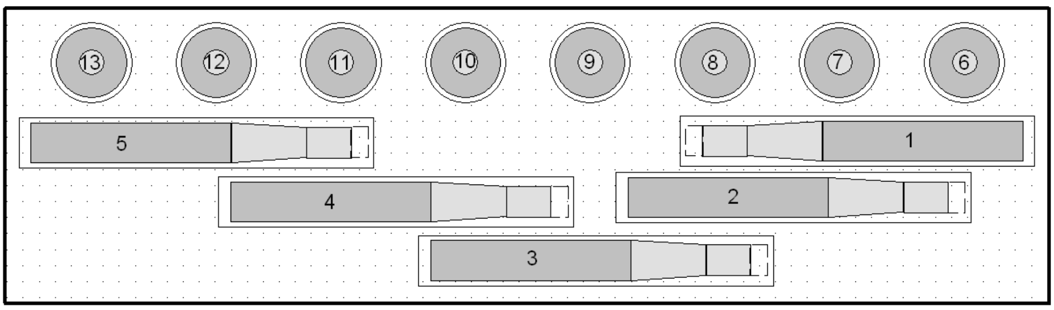


Figure 1: Synergy 2 detector layout: 1 – 5 NaI detectors, 6 – 13 FIDLER detectors.

Other beach areas monitored are the most recent tide-line (referred to as the Strandline) and the line of wind-blown debris or highest tide-line (referred to as the stormline). These survey areas are included in the CEAR (EA, 2016) and have been part of the wider environmental monitoring programme since 1983.

Much of the monitoring of the most recent tide-line is conducted using the vehicle mounted Groundhog Synergy 2 system. However, monitoring of the stormline often requires access to areas of the beach that cannot be safely traversed by the vehicle mounted equipment hence walked surveys are required. These surveys are conducted between Drigg and St. Bees (with the exception of Nethertown beach where the rocky foreshore cannot be safely monitored) using the following methods:

- Surveys conducted by Nuvia Ltd use a single 76 x 400 mm detector crystal of NaI, mounted in a lightweight case, carried between two operators; and,
- Surveys conducted by Sellafield Ltd staff use a FIDLER probe for low energy photons. These surveys are part of Sellafield Ltd's wider environmental monitoring programme, which includes the requirement to complete biannual FIDLER probe monitoring of the extreme high water mark and wind-blown debris between Drigg Point and St. Bees Head.

3 Monitoring Conducted During 2016/17

This section covers the large area beach monitoring programme. It does not cover the strandline monitoring that has been carried out routinely by Sellafield Ltd (reported regularly to EA as part of the Sellafield statutory environmental monitoring programme). For the beach monitoring programme, information is presented on the areas monitored and the challenges presented. The number of finds recovered during monitoring and their distribution on beaches surrounding Sellafield are described. Results from the 2016/17 programme are compared with those from previous years to identify any changes that may affect the overall risk to beach users.

3.1 Changes to Beach Find Dataset

Changes to the beach find categories have also been implemented and the ‘Stone’ category has been replaced by an ‘Object’ category. This change has been applied because finds within the previous stone category consisted of a range of different find types including: granules, gravel, pebbles, stones *etc*.

The beach monitoring dataset has gone through a review process to address a number of particles to object corrections. Periodically, batches of particles are sent to a contract laboratory for further analysis. Detailed size analysis of these particles has shown that 32 have dimensions greater than 2 mm, and therefore should have been categorised as objects. The initial categorisation of a beach find is done when the item is recovered and packaged on the beach, and at times, it is difficult for the operators to assess exactly which item is the radioactive find in a bag containing a variety of different sediment sizes. If at all unsure, the operators always conservatively classify a beach find as a particle.

In addition to the above, all ^{226}Ra finds have been removed from the dataset as they are naturally occurring items which are not related to Sellafield operations.

3.2 Planned Beach Monitoring For 2016/17

The EA places a statutory monitoring requirement on Sellafield Ltd to deliver a large scale beach monitoring programme. This is part of an agreed programme of works as specified in the current Compilation of Environment Agency Requirements (EA, 2016) (see Section 6.1).

The on-going aim of the programme is to continue to provide reassurance that the overall risks to beach users are not greater than those estimated in the Health Protection Agency (HPA) risk assessments (Brown & Etherington, 2011; Etherington, *et al*., 2012a).

The HPA risk assessment (Brown & Etherington, 2011; Etherington, *et al*., 2012a) recommends *“… continued regular monitoring of Sellafield beach and monitoring at one or two other beaches with high public occupancy will provide regulators and the public with continued reassurance that risks associated with radioactive objects in the environment remain very low.”*

A programme of 160 ha was developed and agreed with the EA at the start of 2016 to meet the primary aim of providing reassurance that overall risks to beach users remain at or below those estimated in the HPA risk assessment. As in previous years the programme ran from the start of April 2016 to the end of March 2017, consistent with the financial year.

The 160 ha was split into three programmes:

- Sellafield programme (totalling 88 ha);
- Near-field programme (totalling 62 ha); and,
- Far-field programme (totalling 10 ha).

The near-field programme focused on the beaches at Seascale, Braystones and St. Bees, whereas the far-field programme focused on Allonby beach. The bulk of the monitoring effort was placed on Sellafield beach in 2016/17.

The target areas that were planned for each beach are given in Table 1, with the full schedule in Figure 2.

Table 1: Planned area coverage (ha) for each beach in 2016/17.

Programme	Beach	Sellafield	Near-Field	Far-Field	Total
Sellafield	Sellafield	88	-	-	88
	Braystones	-	22	-	22
Near-Field	St. Bees	-	20	-	20
	Seascale	-	20	-	20
Far-Field	Allonby	-	-	10	10
Total		88	62	10	160

3.2.1 Sellafield programme

A programme of 88 ha monitoring at Sellafield was developed, to provide reassurance that the find rates and find characteristics on the beach with the highest historic find rates are not changing significantly. This programme scheduled three visits to Sellafield, with a target area of between 22 and 34 ha per visit.

The reasons for selecting the beach at Sellafield for the majority of the monitoring programme are:

- The conceptual site model (Rankine & Jackson, 2014) identified the historic Sellafield discharge lines and their decommissioning as the most probable source of the particles being recovered from West Cumbrian beaches;
- Sellafield beach has the highest recorded find rates and is in close proximity to the Sellafield site, with the majority of beta rich particles and almost all objects being recovered from this beach;
- Monitoring of the widest possible extent of the beach at Sellafield should enable the distribution of finds in this area to be better understood and should give a clearer picture on the repopulation of finds both at Sellafield, but also to the beach area to the north at Braystones; and,
- Past monitoring efforts have seen a reduction in find numbers following the introduction of the various developments of the Groundhog system, but these have typically taken three to four years to be realised. Increasing the monitoring rate to approximately twice that of previous programmes may reduce the time taken to observe falling find rates at Sellafield.

For continuity with previous programmes, regular monitoring of the 1 ha repeat area was scheduled for Sellafield beach. This repeat area is a defined area of beach where repeated sampling has been conducted for several years. In 2016/17 this area was monitored on seven occasions during the three scheduled monitoring periods, with an additional survey of the area taking place in March 2017 following a storm event. Monitoring was completed inside one tidal cycle, giving a footprint of that area of beach, with each visit typically being at least one month apart.

3.2.2 Near-field programme

A near-field programme was developed to provide information on the distribution of finds, improve the estimate of find rates and the total population of beach finds and to provide reassurance of low find rates on beaches occasionally visited by the public. The latter meets the Committee on Medical Aspects of Radiation in the Environment (COMARE) requirement to monitor the more popular beaches close to the breaks in monitoring around the school holiday periods. In setting the areas a number of factors were taken into account including: historic find distribution, habit survey data and the need to recover finds for analysis.

The reasons for selecting the beaches as part of the near-field programme were:

- **Braystones** has the second highest historic find rate, is a popular public beach and has a community living just above high water and is adjacent to Sellafield beach;
- **St. Bees** has the third highest find rates and is a popular public beach; and,
- **Seascale** has a lower historic find rate when compared to both Braystones and St. Bees beaches although is a popular public beach.

Monitoring of these beaches, particularly at Braystones, allow the statistical analysis of longer term trends as well as the analysis of the radioactivity distribution of the finds (see Section 4).

Each visit to Braystones beach immediately follows visits to the adjoining beach at Sellafield. This is to investigate whether the removal of finds from Sellafield beach also has an impact on the find rates observed at Braystones. Each of these visits spanned two weeks and covered between 6 and 8 ha. The results are discussed in Section 4.2.2.

For St. Bees and Seascale there were five visits to each of these two beaches, with each survey covering 4 ha. The primary focus of these visits was the designated repeat areas, located close to the public access points, supplemented with coverage of recent strandlines and other sandy areas that are readily accessible.

	Week Starting	Beach Monitoring	Sellafield Programme: Area Targets (ha)	Near-Field Programme: Target Area (ha)	Far-Field Programme: Target Area (ha)
Q1 2016/17	04-Apr	Easter Holidays			
	11-Apr	St Bees (1)		4	
	18-Apr	Seascale (1)		4	
	25-Apr	Sellafield (1)	34		
	02-May				
	09-May				
	16-May				
	23-May				
	30-May				
	06-Jun				
	13-Jun				
	20-Jun				
	27-Jun	Braystones (1)		8	
Q2 2016/17	04-Jul				
	11-Jul	St Bees (2)		4	
	18-Jul	Seascale (2)		4	
	25-Jul	Summer Holidays			
	01-Aug				
	08-Aug				
	15-Aug				
	22-Aug				
	29-Aug				
	05-Sep	St Bees (3)		4	
	12-Sep	Seascale (3)		4	
	19-Sep	Walking Strandline Monitoring			
	26-Sep	Allonby (1)			10
Q3 2016/17	03-Oct				
	10-Oct	Sellafield (2)	32		
	17-Oct				
	24-Oct				
	31-Oct				
	07-Nov				
	14-Nov				
	21-Nov				
	28-Nov				
	05-Dec	Braystones (2)		8	
	12-Dec				
	19-Dec	Maintenance Week			
	26-Dec	No Monitoring (Christmas Holidays)			
Q4 2016/17	02-Jan	St Bees (4)		4	
	09-Jan				
	16-Jan	Seascale (4) and Drigg Strandline Monitoring		4	
	23-Jan	Sellafield (3)	22		
	30-Jan				
	06-Feb				
	13-Feb				
	20-Feb				
	27-Feb	Braystones (3)		6	
	06-Mar				
	13-Mar	Walking Strandline Monitoring			
	20-Mar	St Bees (5)		4	
	27-Mar	Seascale (5)		4	
		Cumulative Totals ==>	88 ha	62 ha	10 ha
		OVERALL TOTAL ==>	160 ha		

Figure 2: Beach monitoring programme for 2016/17.

3.2.3 Far-field programme

The far-field programme (10 ha) targets beaches with historically lower find rates. For 2016/17 this resulted in a single visit to Allonby, which is a popular beach with low find rates that are not dissimilar to those observed at Seascale. As with St. Bees and Seascale, the primary focus of this visit was the areas located close to the public access points.

3.2.4 Additional programme aims

In addition, and to address the requirement to include a vehicle based strandline covering the accessible areas between St. Bees Head and Drigg Point, the fourth visit to Seascale beach in January 2017 included strandline monitoring between Seascale beach and Drigg Point.

The sequence of the beach monitoring programmes also takes into account some operational factors:

- There is time in the programme to carry out sufficient maintenance of the monitoring vehicle, Land Rover and equipment;
- During weeks when the amount of available monitoring time (based on tides and sunlight) is high, the target areas are also higher. In contrast when the amount of time available is less the targets are reduced; and,
- Monitoring visits were scheduled throughout the year for each beach to give the best temporal resolution, allowing for repopulation to occur and to provide coverage of the high occupancy beaches close to the school holidays.

3.3 Beach Areas Monitored in 2016/17

3.3.1 Determination of the area monitored

The area that is covered in the monitoring programme is determined using a high accuracy Global Positioning System (GPS) that records the position of the monitoring vehicle or surveyors for walked monitoring. This generates large amounts of raw GPS data that needs to be processed, using a Geographical Information System (GIS) called ArcGIS. Nuvia Ltd provides an estimate of the area monitored during each beach survey (of multiple days), based on the processed data, to show they have achieved the target area specified in the monitoring programme. To ensure that the required area is monitored, Nuvia assess the area by visit using tight GIS processing parameters and remove any overlap between days.

Sellafield Ltd uses data provided by Nuvia to generate daily GIS shape files that can be displayed on a map and provides a measurement of daily monitored area. It is recognised that Nuvia's monitored area assessment for a visit to a beach and the sum of Sellafield Ltd's daily areas over the same period will be different as they are generated in different ways. The 2013/14 annual particles report (Sellafield Ltd, 2014a) describes in detail the difference between the two methodologies.

The Sellafield methodology is very conservative in its calculation of monitored area from the detector point data, typically giving areas up to 7% smaller than those reported by Nuvia. Nuvia's reported coverage is used to maintain compliance with the CEAR, whilst find rates are calculated using the smaller Sellafield Ltd figure. This ensures a degree of conservatism is built into the calculation of find rates for comparison to the values used in the PHE risk assessment.

3.3.2 Areas monitored in 2016/17

The beach monitoring programme for the 2016/17 financial year was completed with a total area of between 175.12 ha (Nuvia estimate) and 166.67 ha (Sellafield Ltd estimate), against a programme target of 160 ha (Table 2, Figure 3 to Figure 6 and Appendix 1). The following data and maps are based on Sellafield Ltd processed data.

Table 2 presents the area monitored in 2016/17 as a percentage of the available area of each beach. The available area is a simple estimate based on the total area of sand/shingle to the mean low water, excluding rocks and other inaccessible areas of the beach and is provided purely for comparative purposes.

Comparing the information in Table 2 with Figure 2 illustrates that the total area monitored was higher than that originally included in the programme, with slightly more area being monitored at Seascale, St. Bees, Braystones and Allonby beaches. It is also notable that a limited amount of monitoring at Drigg beach was also undertaken as part of the strandline monitoring.

Table 2: Beach monitoring conducted during 2016/17.

Programme	Monitoring area	Number of days	Area covered (ha)	Available area (ha)	Monitoring as % of available
Sellafield	Sellafield	94	87.9	53.3	165%
Near-Field	Braystones	28	23.6	18.9	125%
	St. Bees	19	21.9	28.5	77%
	Seascale	17	21.5	81.6	26%
Far-Field	Allonby	8	10.7	136.9	8%
	Drigg	1	1.1	196.7	1%
Total		167	166.7	515.9	32%

3.4 Numbers of Finds Recovered in 2016/17

A total of 254 finds were recovered during the 2016/17 monitoring programme from the beaches surrounding the Sellafield Nuclear Licensed Site (Table 3). Of these, 206 were classified as particles and the remaining 48 were classified as objects[1]. The locations of these finds are shown in Figure 3, Figure 4, Figure 5 and Figure 6. The maps included in Appendix 1 show the distribution of beach finds for all beaches and the areas monitored during each visit.

Once again the majority of beach finds (approximately 98 %) were recovered from Sellafield (82 %), Braystones (10 %) and St. Bees (6 %) beaches during 2016/17. In excess of 133 ha of beach were monitored at these three locations, which accounted for almost 80 % of the total area surveyed in 2016/17. A total of 48 radioactive objects were detected in 2016/17 and all were recovered from Sellafield beach (Figure 3). Of the 206 particles recovered in 2016/17 the majority were detected on Sellafield beach (78%), with most of the others being from Braystones (12%) and St. Bees (8%).

[1] Objects are defined as >= 2mm in diameter and particles are < 2 mm in diameter. A beta-rich beach find has a positive ^{137}Cs activity greater than its ^{241}Am activity. A ^{60}Co-rich beach find has a positive ^{60}Co activity greater than its ^{137}Cs activity. An alpha-rich beach find has a positive ^{241}Am activity greater than its ^{137}Cs activity.

A total of 209 finds (161 particles, 48 objects) were recovered from Sellafield beach during 2016/17, compared with 289 finds in 2015/16. Monitoring during 2016/17 focused on areas identified as having the highest rates of beta rich finds. The area monitored during this period is comparable with the previous 12 months (88 ha in 2016/17, 83 ha 2015/16).

The appearance of clusters of beach finds within the repeat area at Sellafield (see Figure 3) is a result of the repeat area being monitored on eight occasions. Monitoring operations at Braystones, St. Bees and Seascale largely focused in and around the repeat areas, and as a consequence, a high percentage of the finds recovered during the 2016/17 programme were located within these target areas.

Monitoring at Braystones directly followed every Sellafield visit to see if the find rates at Braystones were affected by the extended monitoring campaigns on its neighbouring beach. To date, there is no evidence of a statistically significant long-term decline in find rates at Sellafield or Braystones beaches that relates to the extended monitoring campaign. Almost 24 ha were monitored at Braystones, with 25 particles detected in 2016/17. Alpha rich particle find rates at Braystones were comparable with the previous year (1.1 finds/ha in 2016/17 and 0.7 finds/ha in 2015/16) and well below the peak Synergy 2 levels recorded for Braystones in 2014/15 (3.0 finds/ha).

Five separate surveys were scheduled for St. Bees throughout 2016/17, with 19 days of monitoring completed during this period. A total of 21.9 hectares of beach was surveyed with 16 particles detected. There was a reduction in the number of finds detected at St. Bees in 2016/17 when compared with the previous year as 34 particles were recovered in 2015/16. Finds rates at St. Bees were approximately half of those observed in 2015/16 and the lowest since the introduction of Synergy 2.

Monitoring at Seascale was conducted over 17 days (totalling of 21.5 ha) during 2016/17 with two particles being detected. A single survey, spanning two weeks, took place at Allonby during September and October 2016. This was conducted as part of the far-field programme to provide reassurance for areas where the general public spend the majority of their time (Figure 6). A total of 10.7 ha were monitored during the survey and no radioactive finds were detected.

There were two alpha rich particles recovered from Drigg beach when the annual vehicle strandline monitoring was completed in January 2017. A small number of finds, combined with a small amount of area monitored results in highly variable find rates which are not representative of wide area averages. Similar variations in find rates over small areas have been recorded in previous years. Find numbers recovered each year will vary according to the area monitored so find rate per hectare values are often a more useful measure than the absolute find numbers. An assessment of find rates is therefore included later in this report (Section 4.2).

Table 3: Particle and object beach finds recovered during 2016/17.

Programme	Monitoring area	Particles recovered in 2016/17	Objects recovered in 2016/17	Total in 2016/17
Sellafield	Sellafield	161	48	209
Near Field	Braystones	25	0	25
	St. Bees	16	0	16
	Seascale	2	0	2
Far field	Allonby	0	0	0
	Drigg	2	0	2
Total		206	48	254

Note 1: Two ^{226}Ra objects were detected in 2016/17 but have been removed from the beach finds dataset as they are natural occurring items and are not related to Sellafield operations

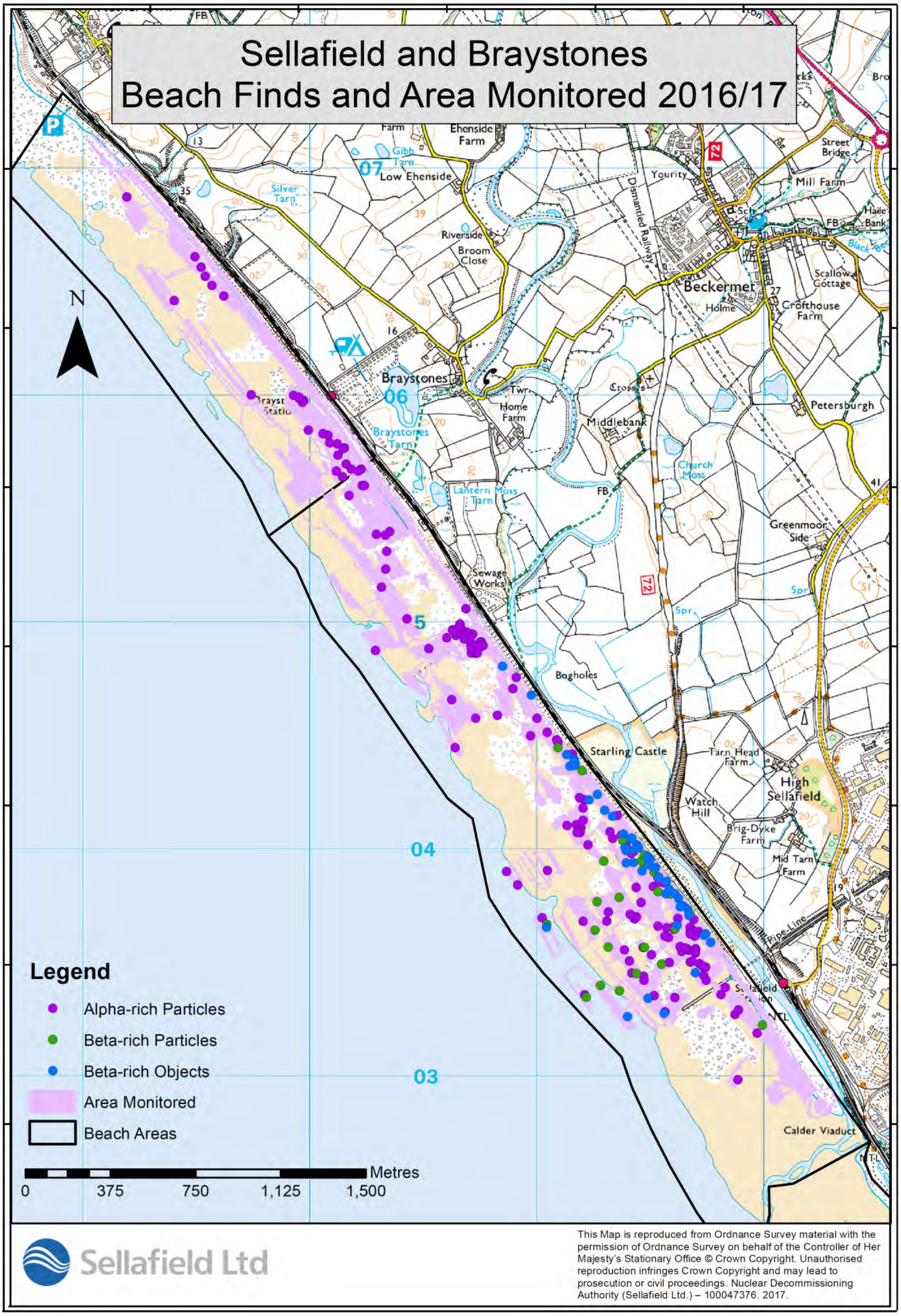


Figure 3: Sellafield and Braystones beach find locations and areas monitored in 2016/17.

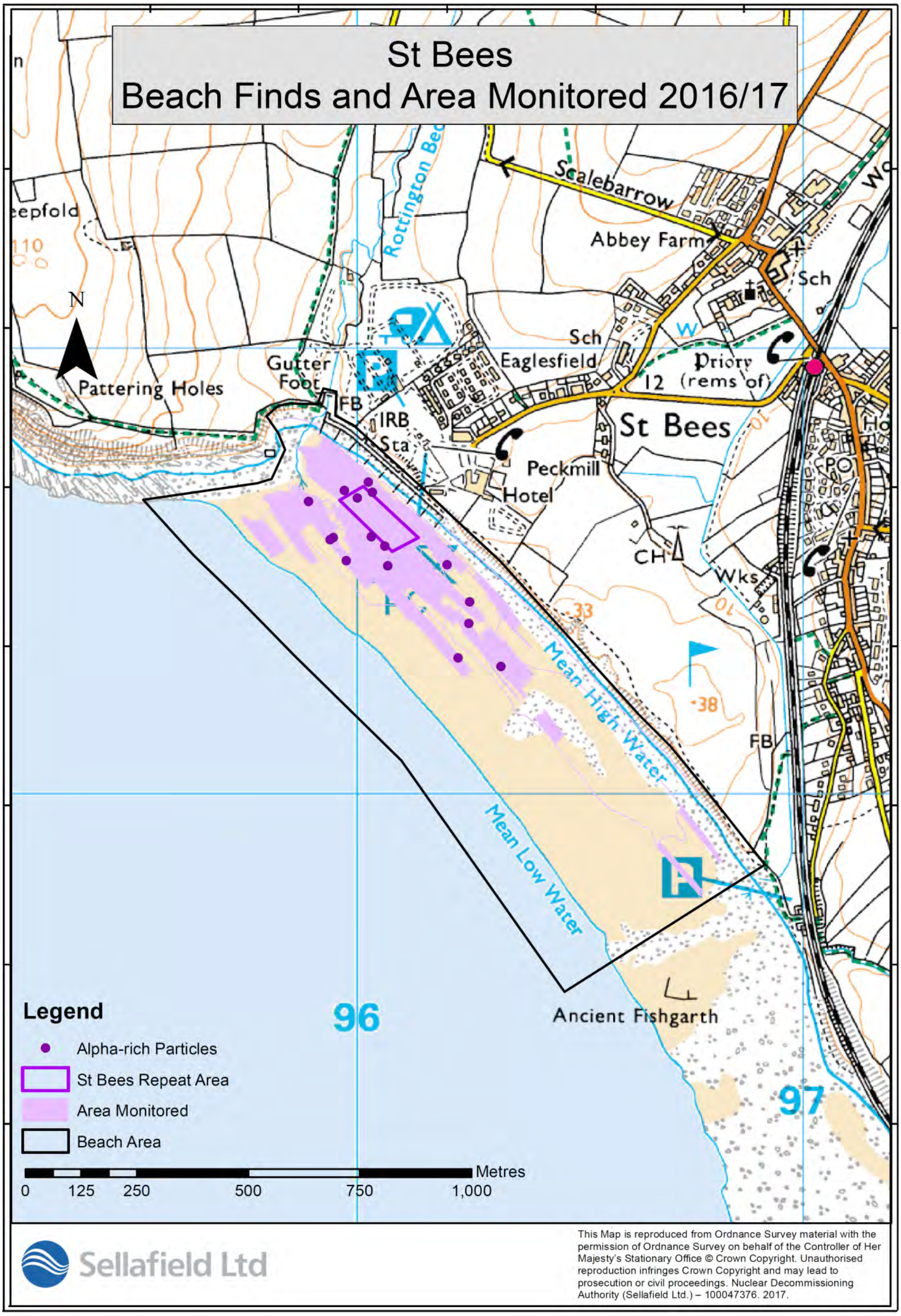


Figure 4: St. Bees beach find locations and areas monitored in 2016/17.

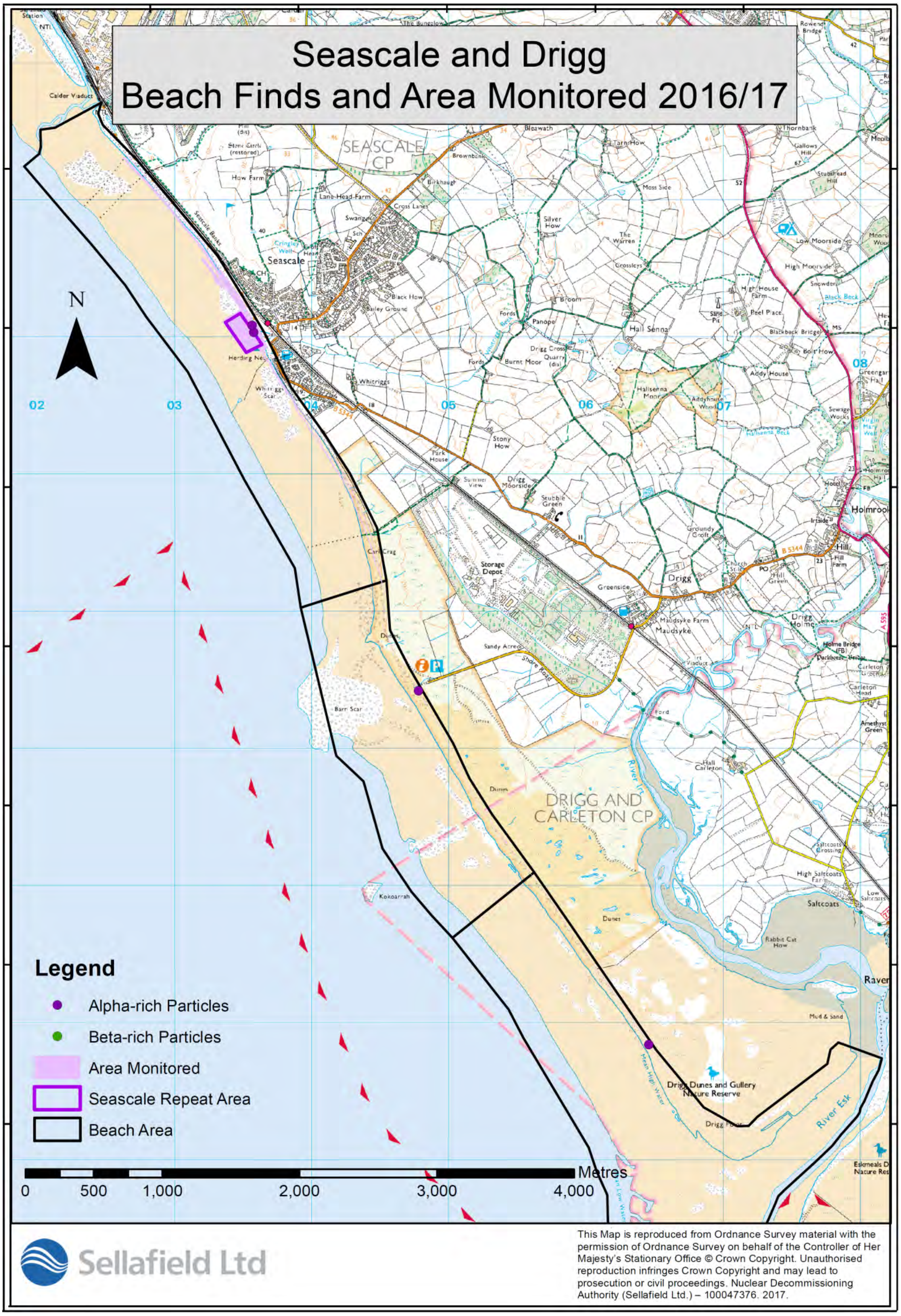


Figure 5: Seascale and Drigg beach find locations and areas monitored in 2016/17.

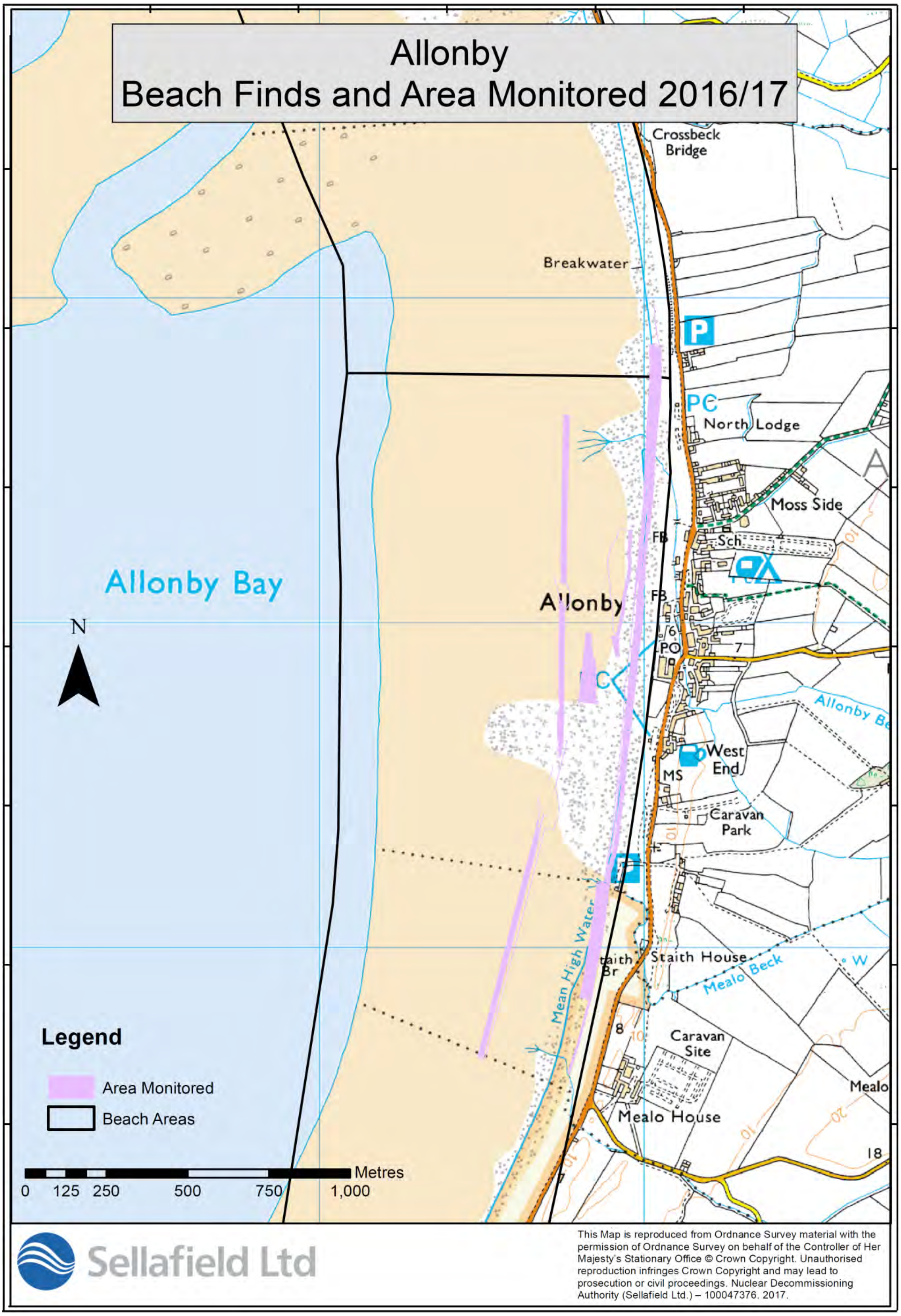


Figure 6: Allonby beach find locations and areas monitored in 2016/17.

3.5 Types of Beach Finds Detected During 2016/17

The key radionuclides detected by the Groundhog Synergy 2 monitoring are ^{137}Cs and ^{241}Am and to a lesser extent ^{60}Co. Consequently, initial characterisation of each find recovered via the monitoring programme concentrates on these isotopes.

For positive analytical results:

- Finds with ^{241}Am activity greater than ^{137}Cs activity are classified as alpha rich.
- Finds with ^{137}Cs activity greater than ^{241}Am activity are classified as beta rich.
- Finds with positive ^{60}Co activity greater than the ^{137}Cs activity are classified as cobalt-rich.
- Finds with a contact beta gamma dose rate in nSv/hr greater than 15 times the ^{137}Cs activity in Bq and not alpha rich and not cobalt-rich are classified as excess beta (*i.e.* a pure beta emitter such as ^{90}Sr may be present).

Over 70 % of all finds recovered in 2016/17 were classified as alpha rich (Table 4). There were 74 finds classified as beta rich in 2016/17, with all beta rich finds recovered from Sellafield beach.

In total, 209 finds were recovered from Sellafield beach (Table 5). Of these, 161 were classified as alpha rich, 74 as beta rich. The number of objects recovered from Sellafield beach during 2016/17 decreased slightly when compared to 2015/16 (48 versus 61). The type and total number of finds detected since large area beach monitoring began in 2006/07 are displayed in Table 6.

Table 4: Numbers of finds by type and classification since 2006.

Classification	2006-2010 Evolution	2010-2014 Synergy	2014/15 Synergy 2	2015/16 Synergy 2	2016/17 Synergy 2	Total
Alpha rich Particle	193	843	307	264	180	1786
Alpha rich Object	4	2	0	0	0	6
Alpha rich Finds	**197**	**845**	**307**	**264**	**180**	**1793**
Beta rich Particle	208	85	35	24	26	374
Beta rich Object	432	80	41	61	48	655
Beta rich Finds	**640**	**165**	**76**	**85**	**74**	**1040**
Cobalt rich Particle	8	5	0	1	0	14
Cobalt rich Object	4	0	0	0	0	4
Cobalt rich Finds	**12**	**5**	**0**	**1**	**0**	**18**
All	**849**	**1015**	**383**	**350**	**254**	**2851**

Note 1: the single find recovered by seabed grab sampling (April 2012) is **not** included in the totals for 2012/13.

3.6 Unusual Finds Detected During 2016/17

As part of the surveillance of the beach monitoring programme the EA require that Sellafield Ltd notify them of any unusual finds that are detected (EA, 2017).

Two finds detected during 2016/17 exceeded the characterisation triggers set within the draft EA intervention criteria.

- A beta rich particle (S1759) was detected in April 2016 on Sellafield beach with a ^{137}Cs activity of 1.01E+05 Bq.
- A beta rich particle was detected in May 2016 on Sellafield beach with a ^{137}Cs activity of 1.03E+05 Bq

Both finds were within the range of previous measurements and therefore did not require immediate further consideration and did not challenge the PHE risk assessment. However, as they contained more than 1E+05 Bq of ^{137}Cs, they were sent for more detailed laboratory analysis in December 2016.

When separated from the rest of the sample by the contracted laboratory, particle size analysis has shown that the April 2016 find was measured as having dimensions of 4 x 3 x 2 mm and has been re-categorised as an object. Likewise, the May 2016 find is also an object, with dimensions of 9 x 5 x 3 mm.

Table 5: Find numbers by type recovered during 2016/17.

Monitoring area	Alpha rich	Beta rich	Cobalt rich	Total in 2016/17
Allonby	0	0	0	0
St. Bees	16	0	0	16
Braystones	25	0	0	25
Sellafield Particles	135	26	0	161
Sellafield Objects	0	48	0	48
Seascale	2	0	0	2
Drigg	2	0	0	2
Total	180	74	0	254

Table 6: Find numbers by type recovered since 2006/07.

Monitoring area	Alpha rich	Beta rich	Cobalt rich	Total
Allonby particles	13	2	0	15
Workington particles	5	1	0	6
Workington objects	0	1	0	1
Harrington particles	4	0	0	4
Whitehaven particles	8	1	0	9
St. Bees particles	233	15	2	250
Braystones particles	402	35	4	441
Sellafield particles	1034	299	8	1341
Sellafield objects	6	657	2	665
Seascale particles	63	23	0	86
Seascale objects	0	3	1	4
Drigg particles	25	2	0	27
Drigg objects	0	1	1	2
Total finds	1793	1040	18	2851

Note 1: the single find recovered by seabed grab sampling (April 2012) is not included in the totals for 2012/13.

4 Data Analysis Review

4.1 Spatial Analysis of Beach Finds

To investigate if there is any correlation between find characteristics and the find location, the beach monitoring GIS has been used to generate find rate maps along the coast between St. Bees and Drigg point. This was achieved by dividing the coast up into 100 m grid cells (note that the area of each cell equals 1 ha) and calculating the total area monitored within each cell and the total number of finds (accounting separately for alpha rich particles, beta rich particles and beta rich objects). It should be noted that ^{60}Co rich finds could not be analysed statistically due to the low number recovered. As the differences between Synergy and Synergy 2 monitoring technology are small, the data were combined for this analysis. Find rates were also found to be highly uncertain when they related to small amounts of monitoring within a cell, hence data were filtered so that find rates are only presented when more than 1 ha of monitoring occurred in a grid cell.

Find rate maps are shown in Figure 7 and are summarised in Figure 8, which illustrates that alpha rich particles finds are predominantly recovered to the north of the Sellafield discharge pipeline with a peak to the north (at around 1-2 km) and a gradual decay with distance. There is a discontinuity in Figure 7 and Figure 8 as monitoring cannot be conducted between the northerly edge of Braystones beach and the southerly edge of St. Bees beach due to the nature of the beach. Beta rich particles and objects were found to be more tightly clustered, with again a peak at approximately 100 - 200 m to the north of the pipeline.

Work conducted on coastal geomorphology and sediment transport (detailed in Section 5) illustrated that the northerly movement of particles would be expected based on coastal processes and that the differences between alpha rich and beta rich particle find rate distributions may be due to differences in timing of the release or the distances from the beach that particles were released.

4.2 Find Rates per Hectare

4.2.1 Find rate trend analysis

The analysis of the spatial distribution of find rates shown in Figure 8 illustrate that find rates are not consistent spatially and that the peaks of the distributions of alpha rich particles, beta rich particles and beta rich objects all occur on Sellafield beach. However, it is also clear that the shapes of these distributions differ between the three types of finds, with alpha rich particles being the most dispersed, with the most northerly peak and beta rich objects being the least dispersed, with a peak closest to the point the sealines cross the beach. The consequence of this is that trends in peak find rates can only be compared for fixed locations. This is clearly much less of an issue for beaches distant from Sellafield beach (*i.e.* St. Bees).

The geographic locations of the spatial peaks in find rate were determined along with their Standard Deviations and these were used to define fixed locations to allow the comparison of find rates over time. Find rate data were found to show considerable variability when they were averaged over small areas. Hence, find rates were averaged over areas of approximately 10 ha (or approximately 2-3 weeks of monitoring effort) which was found to be suitable to allow trending.

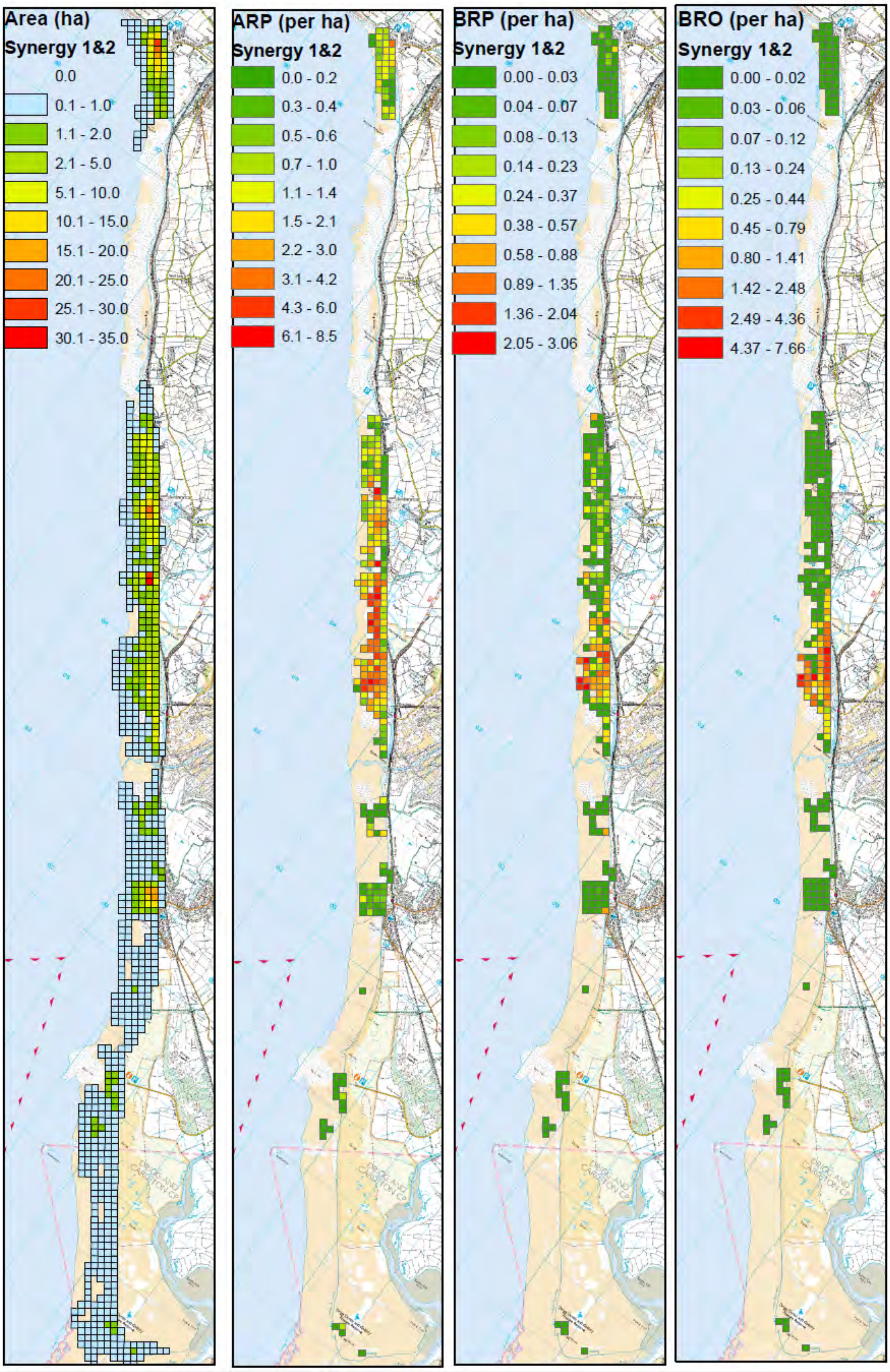


Figure 7: Find rate map for the Synergy and Synergy 2 monitoring periods combined subdivided into the area monitored (ha), alpha rich particle find rate (ha^{-1}), beta rich particle find rate (ha^{-1}) and beta rich objects find rate (ha^{-1}).

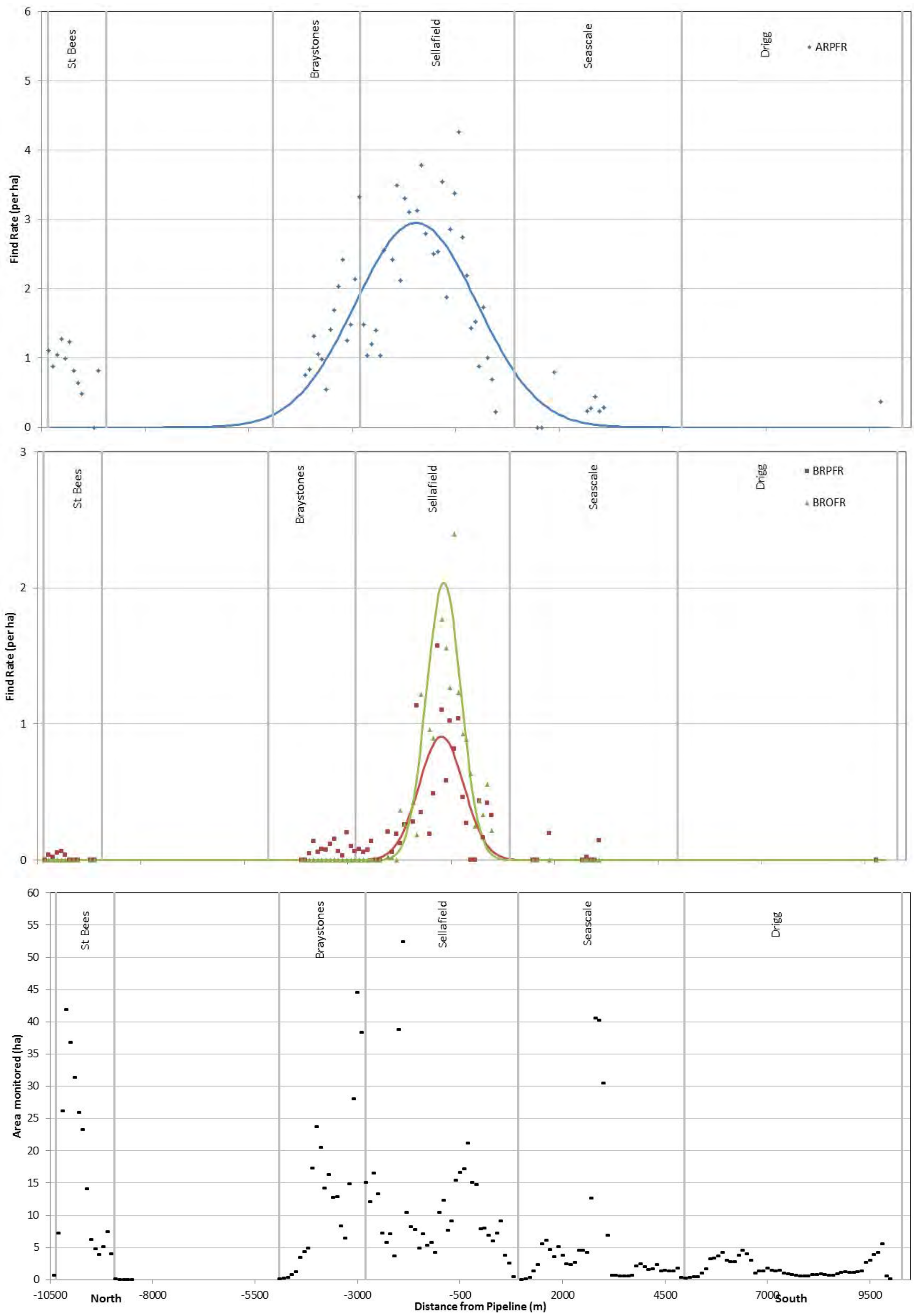


Figure 8: Spatial distribution of find rates for alpha rich particle (blue), beta rich particles (red), beta rich objects (green) and the monitoring areas (black) along the beaches (for Synergy and Synergy 2 data combined).

ARPFR - Alpha Rich Particle Find Rate, BRPFR - Beta Rich Particle Find Rate, BROFR - Beta Rich Object Find Rate.

The resulting graphs are shown in Figure 9 and illustrate that:

- Alpha rich particle find rates increased significantly when the Synergy monitoring system was introduced due to its increased sensitivity to ^{241}Am. Since then find rates have been reasonably constant, with the increase recorded when Synergy 2 was introduced being found to be temporary, with find rates quickly declining to levels that were within the range of data recorded by the previous Synergy system.
- Beta rich particle and object find rates reduced quickly when monitoring began with the Evolution System in 2006. Since then they have remained reasonably constant.

Monitoring during 2016/17 focused on these peak areas to determine whether a concerted monitoring effort can deplete find rates and, potentially, determine the rate of repopulation or mixing of material on the beach. Figure 9 shows that there is no evidence of depletion in find rates to date.

Work has been completed in 2016/17 reviewing Coastal Geomorphology and Sediment Transport (see Section 5.2.1). This work has highlighted the importance of storm events in the dispersion of particles and objects in the environment. Weather data have been gathered from the Sellafield Meteorological tower and data on wave parameters (including height and energy) have been gathered from the Met Offices WaveWatch III 8km dataset. An initial analysis of these data suggests that there is no direct relationship between the occurrence of stormy conditions or high waves and beach finds (Golder, 2017c).

4.2.2 Annual find rates

The annual find rates for each of the beaches that are monitored in West Cumbria, since the introduction of Synergy 2, are shown in Table 7. Table A2.4 in Appendix A shows the breakdown of finds by find types.

These data illustrate that find rates during 2016/17 were within the typical ranges previously observed for all beaches, with a notable decrease in the particle find rate on Sellafield beach since Synergy 2 was introduced, as also shown in Figure 9. Since 2015/16 the monitoring programme has included visits to Braystones following monitoring on Sellafield beach. Whilst reductions in alpha rich particle find rates were found on both beaches following the introduction of Synergy 2 there was no further evidence of correlations between find rates at Sellafield and Braystones following the incorporation of the 2016/17 data. Hence, there is no current evidence that the removal of finds from Sellafield beach also has an impact on the find rates observed at Braystones (see the monitoring plan for 2016/17 in Section 3.2.2).

The annualised alpha rich and beta rich particle find rates following the introduction of the Groundhog Synergy 2 system in May 2014 for the main beaches are shown in Figure 10 and Figure 11. This figure shows that alpha rich particle find rates across all beaches are below the peak Synergy 2 levels, with finds rates decreasing on St. Bees, Sellafield and Seascale beaches when compared to the previous year. All of the beta rich particles detected in 2016/17 were found on Sellafield beach.

Beta rich object find rates over the last three years are displayed in Figure 12. The number of objects recovered during 2016/17 decreased when compared with the previous year (48 in 2016/17, 61 in 2015/16), with all objects being recovered from Sellafield since the introduction of Synergy 2.

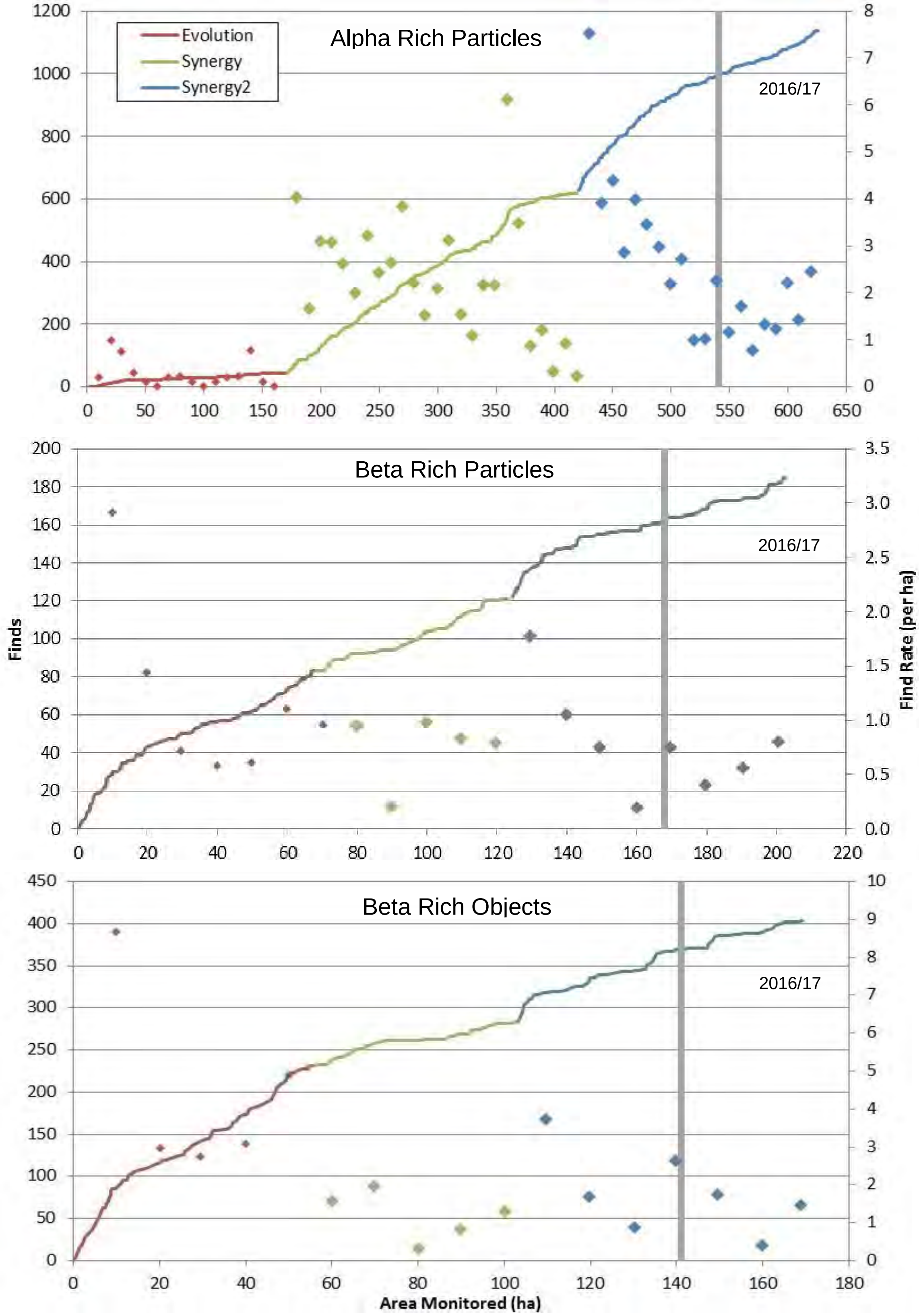


Figure 9: Trends in alpha rich particle, beta rich particle and beta rich object finds with area monitored at the spatial peaks (+/- 1 standard deviation). Points show find rates averaged over 10 ha areas, vertical lines show the start of the 2016/17 monitoring data.

Table 7: Annual alpha rich particle find rates since the introduction of Synergy 2 (finds per hectare).

Monitoring area	2014/15	2015/16	2016/17
Allonby	0.5	No finds	No finds
St. Bees	1.2	1.5	0.7
Braystones	3.0	0.7	1.1
Sellafield	4.6	2.5	1.5
Seascale	0.5	0.2	0.1
Drigg	IA	IA	IA

'IA' indicates insufficient area coverage to estimate finds rates (<10 ha).

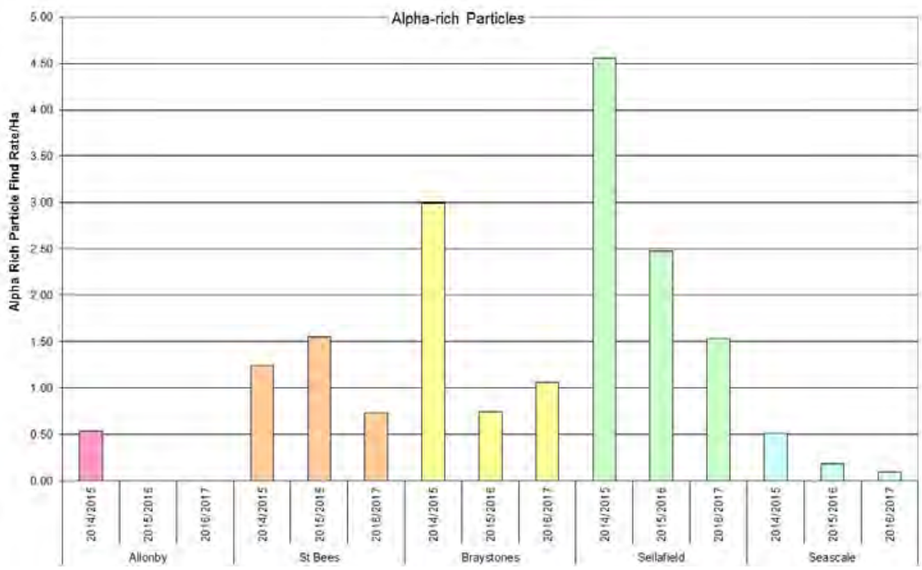


Figure 10: Alpha rich particle find rates since the introduction of Synergy 2.

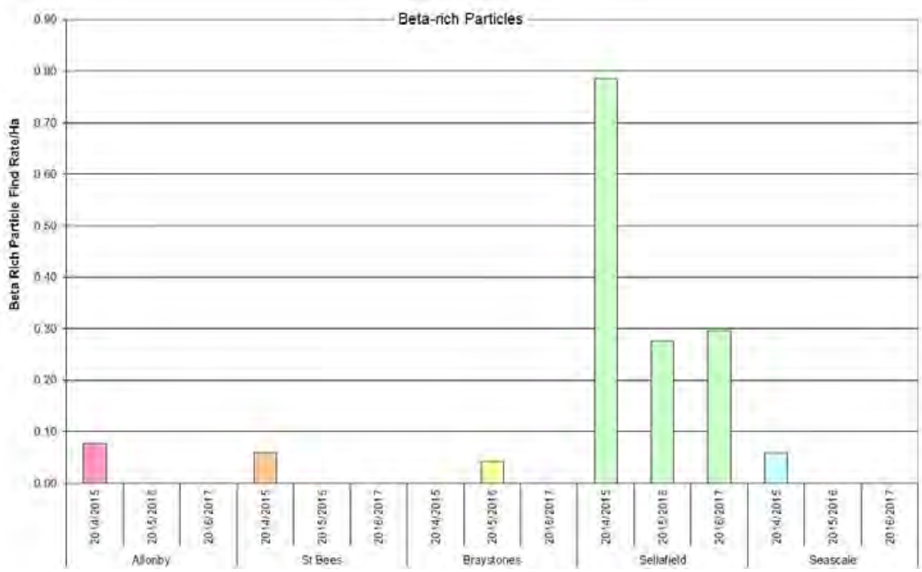


Figure 11: Beta rich particle find rates since the introduction of Synergy 2.

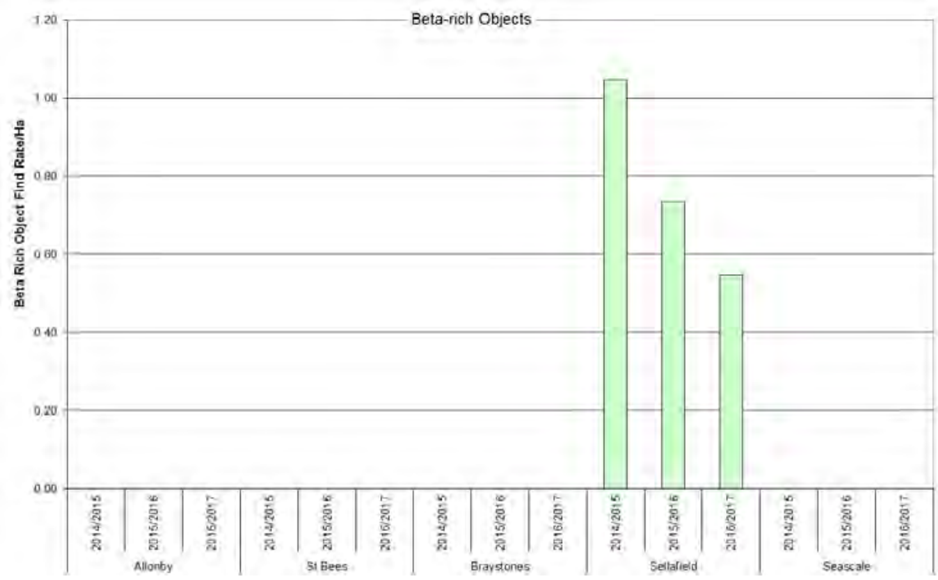


Figure 12: Beta rich object find rates since the introduction of Synergy 2.

4.3 Investigation Monitoring

4.3.1 Repeat area monitoring and analysis

Following their introduction in 2011/12, repeat areas continued to be monitored during visits to Sellafield, Braystones, St. Bees and Seascale beaches (8, 3, 5 and 4 times respectively) during the 2016/17 programme. The purpose of this monitoring is to provide reassurance that the find rates and find characteristics on beaches with the highest historic find rates and highest public occupancy are not changing significantly. At Sellafield, Braystones and St. Bees all the available beach area inside the designated repeat areas was monitored inside one tidal cycle, giving a footprint of that area of beach. At Seascale the repeat area is much larger (> 3 ha) and as a consequence is unable to be monitored in one tidal cycle. The data from previous repeat area monitoring trials has demonstrated that repopulation or mixing of material can occur in as little as two tidal cycles.

The overall find rate in 2016/17 has decreased when compared to the previous two years (2.4 finds ha^{-1} in 2014/15, 2.1 finds ha^{-1} in 2015/16, 1.5 in finds ha^{-1} 2016/17). Table 8 shows that the find rates within the repeat areas were all slightly lower when comparing 2016/17 data against the 2015/16 financial year. Comparing find rates from monitoring inside and outside the repeat areas for Sellafield and Braystones beaches is complicated by the spatial distribution of finds shown in Figure 8. The find rates in the repeat area at Braystones beach are above the overall beach average which is due to the repeat area being located at the southerly limit of the beach, closest to Sellafield beach and the spatial peak in find rates shown in Figure 8. The find rate at St. Bees beach repeat area is a factor of ten lower than in 2015/16, but this is in part an artefact of the defined repeat area. During 2016/17 a total of five finds were recorded just outside the repeat area boundary and a single find within it, so a find rate of up to six times greater might have been recorded using a slightly different definition for the repeat area, see Appendix 1.

An important conclusion from Table 8 is that despite completing repeat area monitoring since 2011/12 there is no evidence of any substantial depletion of find rates within the repeat areas. Hence, the data confirm that the beaches are well mixed which was also a conclusion of the conceptual site model report (Rankine and Jackson, 2014).

Table 8: Find rates for all find types within designated repeat areas.

Beach	Find rate in area monitored		
	2014/15	2015/16	2016/17
St. Bees	2.2	2.1	0.2
Braystones	6.0	4.7	2.9
Sellafield	6.7	5.1	3.0
Seascale	0.5	0.1	0.0

4.4 Find Characterisation

4.4.1 Mixed alpha and beta rich finds

In general, particle finds contain either ^{137}Cs or ^{241}Am at detectable levels, with the other radionuclides being reported as being below the analytical limit of detection. Of the 1788 alpha rich particle finds recovered up to the end of March 2017 only 34 contained measurable levels of ^{137}Cs activity. This is approximately 2 % of the total number of alpha rich finds. Similarly for beta rich particle finds, of the 378 recovered up to the end of March 2017, 43 (or 11 %) contained measurable levels of ^{241}Am activity (Table 9).

Aside from the unusual find recovered from Seascale in June 2014, which had a ^{137}Cs activity of 7.38E+03 Bq, the activity of ^{137}Cs in alpha rich finds is generally relatively low, with the maximum being only 6.09E+01 Bq (Figure 13). For the beta rich finds, the maximum ^{241}Am activity is higher at 1.63E+03 Bq, which is just below the activity of finds recovered by detection of ^{241}Am (Figure 14). From Figure 13 and Figure 14 it can be seen there is no clear relationship between the relative activities.

Relatively few alpha rich objects have been found, with only six recovered to date. Of these, three also contained detectable levels of ^{137}Cs. Of the 662 beta rich objects, 109 also contained detectable levels of ^{241}Am. The relative activities of all the object finds with both ^{137}Cs and ^{241}Am are shown in Figure 15.

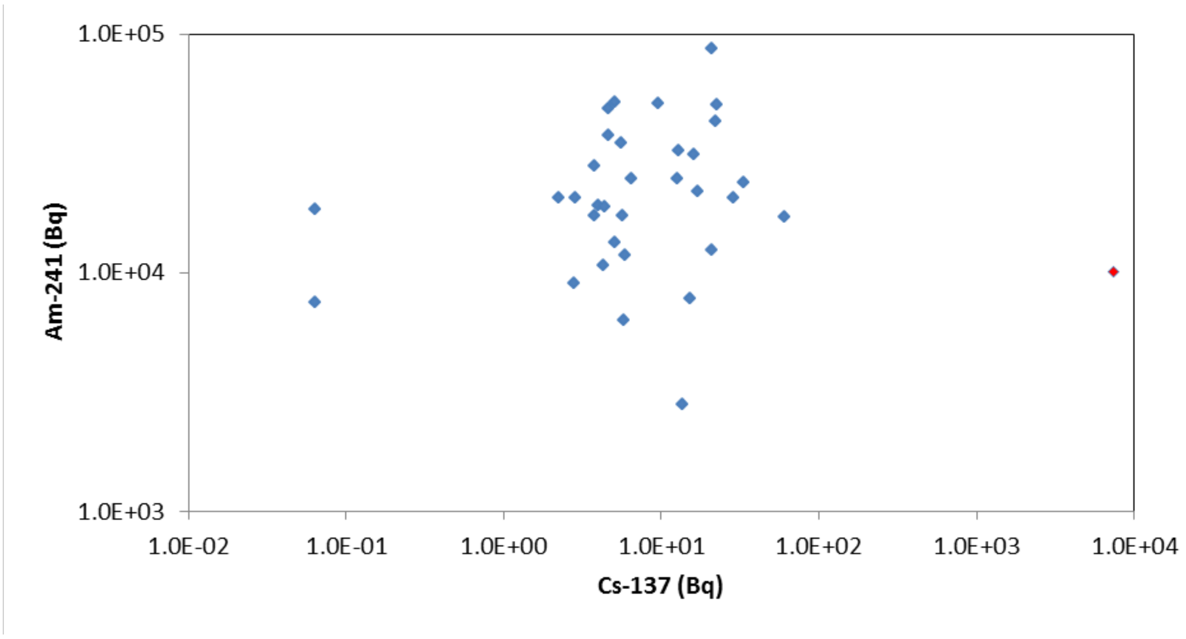


Figure 13: ^{137}Cs activity in alpha rich particle finds.

Note: The unusual Seascale find (S1164) is marked in red. This find contained ^{137}Cs activity of 7.38E+03 Bq and ^{241}Am activity of 1.01E+04 Bq.

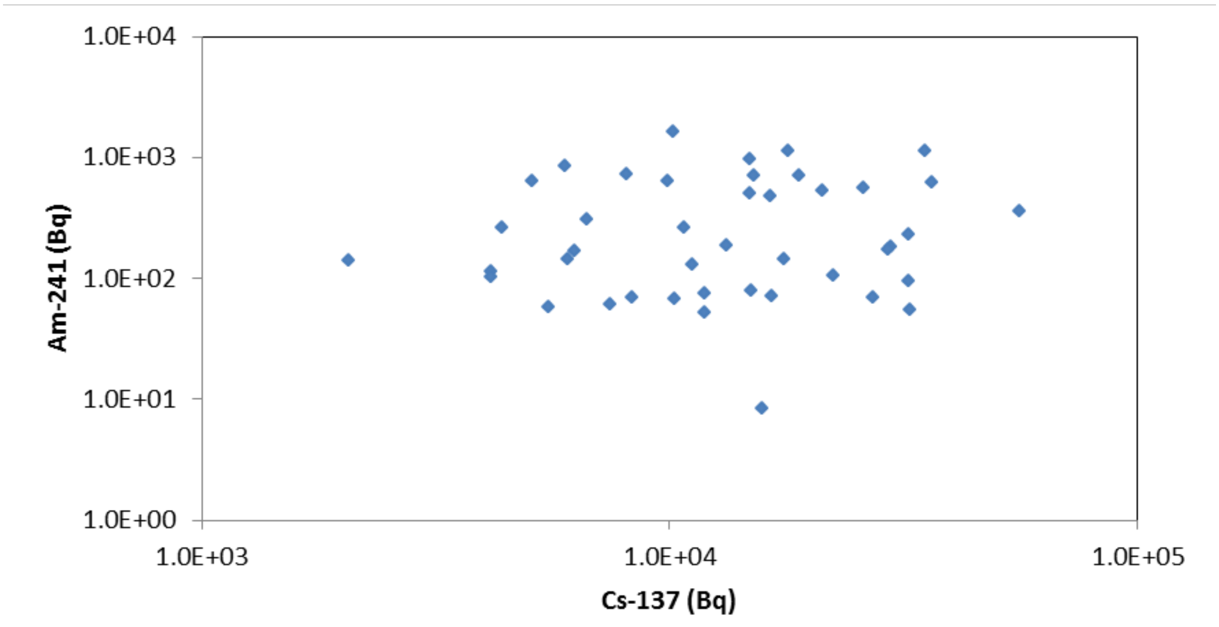


Figure 14: ^{241}Am activity in beta rich particle finds.

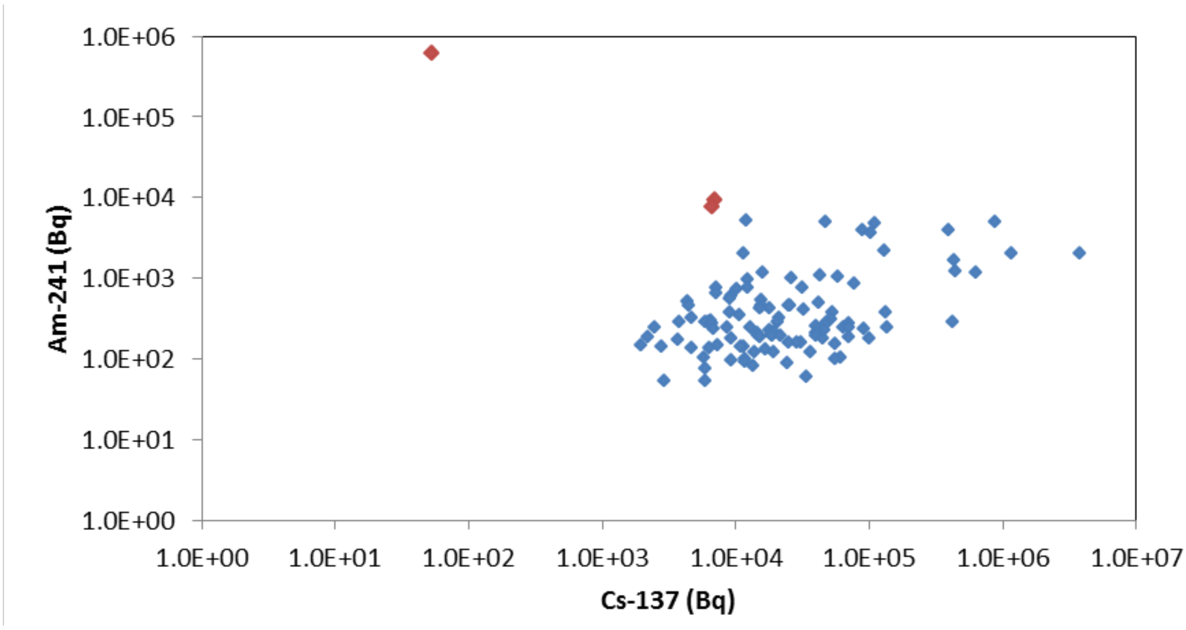


Figure 15: ^{137}Cs and ^{241}Am activity in object finds.

Note: Alpha rich objects marked in red.

4.5 Activity Distribution for ^{137}Cs and ^{241}Am

As noted in the Particles Annual Report for 2015/16, the introduction of Synergy 2 appears to have impacted on the distributions of the activity of particles being recovered. Figure 16 shows that the mean of the distribution of ^{241}Am activity on particle finds reduced with the introduction of Synergy. This was expected as the Synergy system was designed to have an improved detection capability. The introduction of Synergy 2 can be seen to have slightly shifted the activity distribution towards lower activity alpha rich particles (as shown by the reduction in mean from 2.5E+04 Bq to 2.2E+04 Bq going from Synergy to Synergy 2). The reduction in the detection of high activity alpha rich particles could suggest that the population of these highly detectable finds may be being depleted by the monitoring programme.

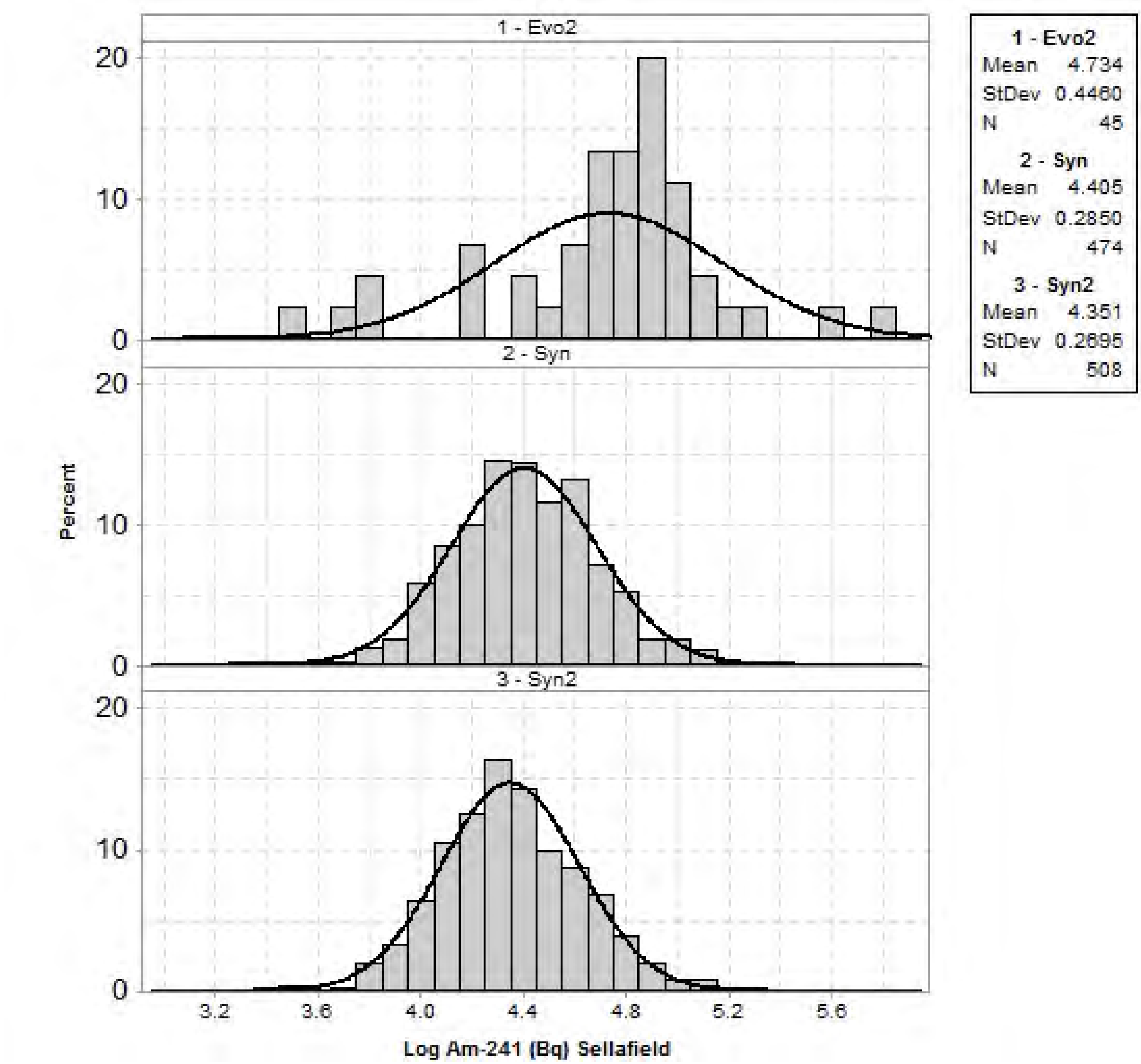
Figure 17 shows that there was also a change in the distribution of detected ^{137}Cs activity when the system was changed from Evolution to Synergy. This was found to be a decrease in the total number of finds detected, with an increase in the mean activity of finds (from 1.22E+04 Bq to 1.45E+04 Bq) and a reduction in the standard deviation. The mean ^{137}Cs activity also increased when going from Synergy to Synergy 2 (from 1.45E+04 Bq to 2.14E+04 Bq) and there was a further reduction in the standard deviation of the distribution. Work is ongoing to establish the causes for these changes in activity distributions, although the most likely explanation is that they are associated with improvements to the standardisation of detector heights on the monitoring equipment.

The distribution of ^{137}Cs and ^{241}Am activities shown in Figure 16 and Figure 17 since Synergy 2 was introduced remain within previously observed ranges, providing reassurance that they are part of the same general population. This is also shown in Figure 18, where the activity distributions measured in 2016/17 are compared with those measured during the previous two years. This provides confidence that the PHE advice remains valid. It is now over seven years since the most active beta rich particle find was recovered (from Whitehaven beach) and over 10 years since the most active alpha rich particle find was recovered (from Sellafield beach).

Table 9: Find Classification since 2006/07.

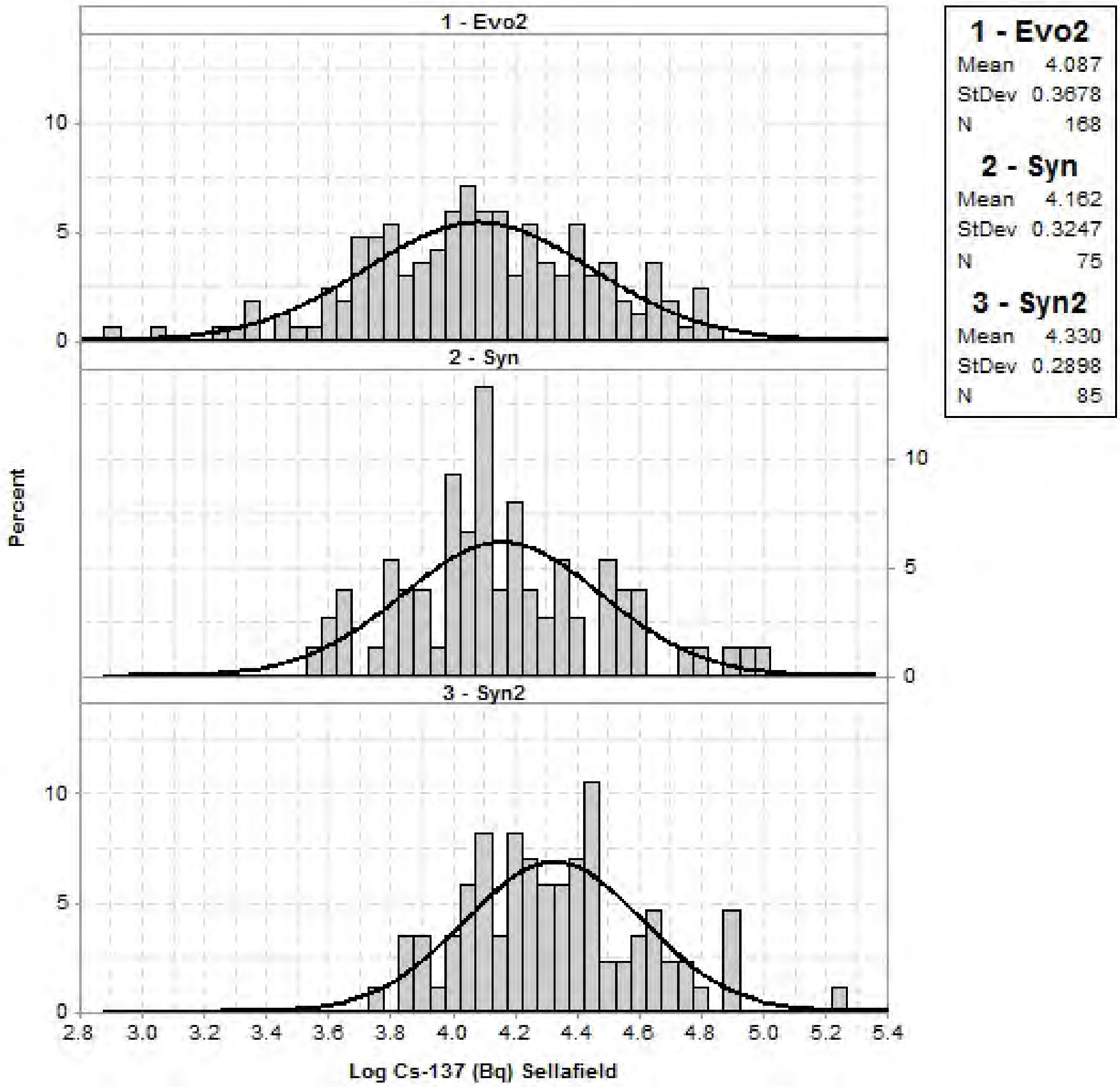
	Alpha rich			Beta rich		
	Pre-Synergy	Synergy	Synergy 2	Pre-Synergy	Synergy	Synergy 2
Total number	62	983	749	599	206	235
No. of particles	59	980	749	190	103	85
No. of objects	3	3	0	409	103	150
Particle mean ^{241}Am (Bq)	7.82E+04	3.00E+04	2.59E+04	3.72E+02	5.45E+02	2.22E+02
Particle max. ^{241}Am (Bq)	6.34E+05	2.52E+05	1.46E+05	1.15E+03	1.63E+03	7.17E+02
Number of particles containing ^{241}Am	59	980	749	17	11	15
Object mean ^{241}Am (Bq)	1.74E+04	2.40E+05	-	7.62E+02	4.15E+02	6.51E+02
Object max. ^{241}Am (Bq)	3.54E+04	6.18E+05	-	4.99E+03	1.17E+03	5.27E+03
Number of objects containing ^{241}Am	3	3	0	59	14	36
Particle mean ^{137}Cs (Bq)	4.09E+01	1.99E+01	3.02E+02	1.51E+04	1.81E+04	2.10E+04
Particle max. ^{137}Cs (Bq)	6.09E+01	3.36E+01	7.38E+03	6.52E+04	2.92E+05	5.91E+04
Number of particles containing ^{137}Cs	2	7	25	190	103	85
Object mean ^{137}Cs (Bq)	7.04E+03	5.46E+01	-	3.94E+04	5.94E+04	9.22E+04
Object max. ^{137}Cs (Bq)	7.20E+03	5.46E+01	-	8.75E+05	1.04E+06	3.73E+06
Number of objects containing ^{137}Cs	2	1	0	409	103	150

Note: Full set of find classification details given in Appendix 2, Table A2.3.



Note: Log scales have been used hence, Log 3 = 1,000 (1E+03); Log 4 = 10,000 (1E+04) and Log 5 = 100,000 (1E+05).

Figure 16: Distribution of ^{241}Am activity of alpha rich particle finds by monitoring technology type for vehicle surveys at Sellafield beach.



Note: Log scales have been used hence, Log 3 = 1,000 (1E+03); Log 4 = 10,000 (1E+04) and Log 5 = 100,000 (1E+05).

Figure 17: Distribution of ^{137}Cs activity of beta rich particle finds by monitoring technology type for vehicle surveys at Sellafield beach.

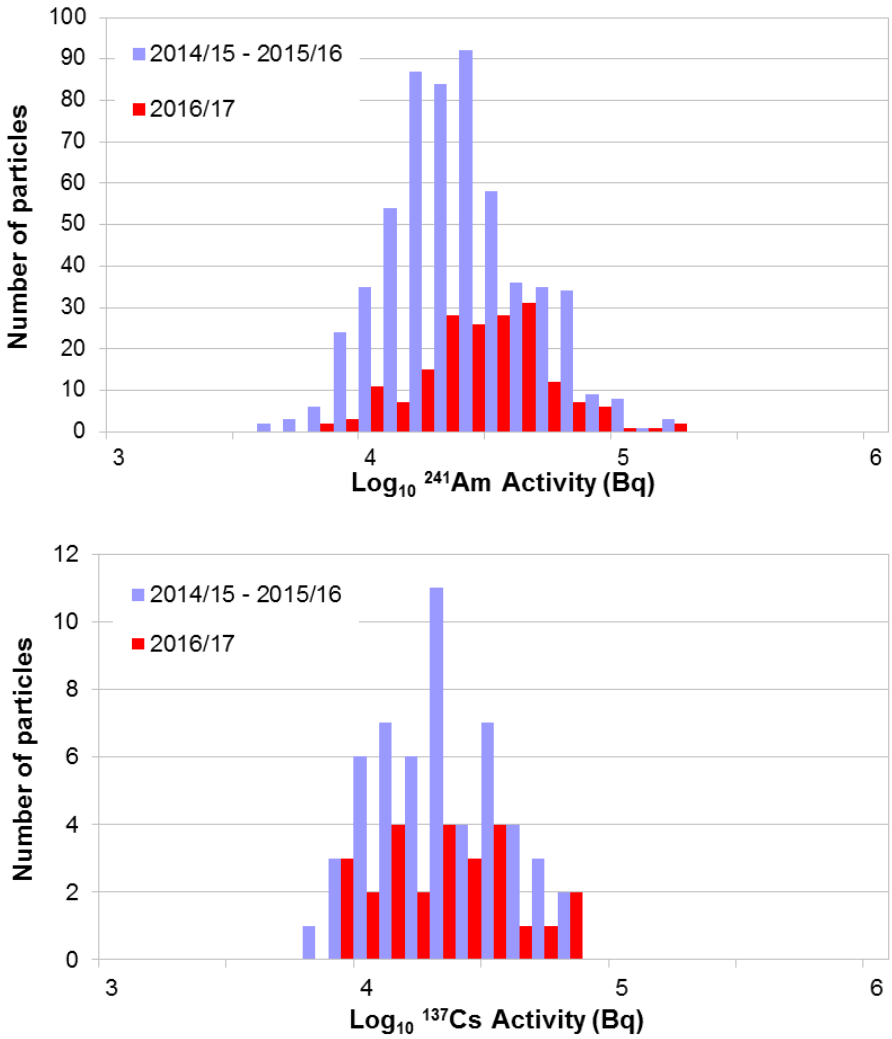


Figure 18: Radioactivity of finds classified as alpha-rich particles (upper) and beta rich particles (lower).

4.6 Further Analysis of Beta Rich Particle Finds

4.6.1 Analytical approach

Laboratory analyses were performed on a selection of beta rich finds to provide information on the activity concentrations of ^{90}Sr and other beta emitting radionuclides and skin doses. Analysis of an alpha rich find was also performed in order to compare physical characteristics with those of a beta rich find from the same beach. Discussions of these data are given below and complement those given in the recent annual reports (Sellafield, 2015; 2016).

The inventory of beach finds submitted for physical and radiochemical analyses to Golder Associates (UK) Ltd (Golder, 2017a;b) for further analysis within the Environmental Framework project ESR199 consists of:

Batch 1	10 samples	May 2016
Batch 2	9 samples	December 2016

Golder has co-ordinated beta rich find analytical investigations through the use of two organisations as shown in Table 10.

Table 10: Analysis conducted through the ESR 199 contract in 2016/17.

	Public Health England (PHE)	British Geological Survey (BGS)	Public Health England (PHE)
Non destructive	Particle isolation; Dose rate measurements; High resolution gamma spectrometry (HRGS); Dose rate measurements using small volume ion chambers, Gafchromic film and Thermoluminescence Devices (TLD).	Scanning Electron Microscopy (SEM) imaging; Energy Dispersive X-ray (EDX) analysis.	
Destructive	Total dissolution – mineral acids, microwave digestion; Metal analysis by Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES) and ICP Mass Spectrometry (ICP-MS);		Radiochemical analyses on selected digested particle solutions*.

* Radiochemical analysis are used to determine: ^{90}Sr; $^{234,235,238}U$; $^{238,239,240}Pu$; ^{241}Pu; ^{241}Am and Cm alpha isotopes.

The specific types of physical and radiochemical analyses that have been and are being undertaken on the selected alpha and beta rich finds have been described previously (Sellafield, 2015; 2016).

The following criteria were used to select the ten beach finds submitted in May 2016:

- Any particle with ^{137}Cs activity greater than 1E+05 Bq to be analysed. Prior to 2 June 2015, all particles satisfying these criteria had been analysed. No finds in this batch had ^{137}Cs activities greater than 1E+05 Bq;
- Select four particles that have the highest ^{137}Cs activities that have not been analysed yet (6.33E+04 to 7.75E+04 Bq);
- Regarding beta/gamma dose rate, select five particles that give the highest dose rate that have not been analysed to date (1.0E+05 to 1.3E+05 nSv hr^{-1}); and,
- Unusual finds/finds of interest – analysis of an alpha rich and a beta rich find in the same year (2014) from Allonby beach.

The following criteria were used to select the nine beach finds submitted in December 2016:

- Any particle with ^{137}Cs activity greater than 1E+05 Bq to be analysed. Three finds sent (finds later identified as 'objects' rather than 'particles');
- Select two particles that have the highest ^{137}Cs activities that have not been analysed yet (7.2E+04 to 7.6E+04 Bq);
- Regarding beta/gamma dose rate, select three particles that give the highest dose rate that have not been analysed to date (all 1.0E+05 nSv hr^{-1}); and,
- Unusual finds/finds of interest – highest ^{137}Cs activity of 'Alpha/beta hybrid' particles (4.7E+04 Bq) and only remaining 'Excess beta' particle not yet analysed (^{137}Cs 4.4E+03 Bq).

During 2016/17, contact dose measurements and HRGS were performed on all 19 beach finds. All finds have been dissolved in mineral acids and have undergone radiochemical analysis for gross alpha and beta (19), ^{90}Sr (18), U (5), Pu (6) and Am/Cm (6) activity by PHE.

The analytical details of the 19 finds are presented and discussed below.

4.6.2 Petrographic results and conclusions

Based on SEM and EDXA analysis of the likely source materials from which finds have originated, the 19 finds have been grouped in to 5 categories, as listed below. The first 2 categories contain 15 finds and comprise natural mineral materials originating from rocks and sediments; the next 3 categories contain 4 finds and comprise materials of anthropogenic origin - zirconium-rich, plutonium-bearing and graphite.

4.6.2.1 Naturally occurring Biotite mica (3 finds)

Biotite mica is a mineral found in many rock types. The chemical composition of the biotite particle suggests partial alteration to chlorite. These finds have a somewhat atypical (for biotite) physical appearance, similar to that seen in previous studies. Sources for their radioactivity were not detectable at their surfaces. Patchy thin surface deposits containing Fe and P (locally with some Cr) could contain adsorbed radioactive species. Alternatively, micas represent potential sites for Cs fixation by irreversible cation-exchange for K. The micas are micro-fractured. The angular edges of some planar (cleavage) surfaces show that recent flaking has occurred. These micas have a significant fragmentation risk.

4.6.2.2 Naturally occurring rock fragments (12 finds)

These are all of silicate rock types, six with sedimentary origins, six with igneous origins. Seven are >2 mm in size so are classified as 'objects' under the Sellafield Ltd classification scheme. The sedimentary types are a fine grained sandstone, silty mudstone, a muddy siltstone, a siltstone and a probable meta-sediment. These all contain significant mica, particularly the silty mudstone which may be a meta-sediment. Whilst the siltstone find is highly porous the other two are of low porosity. The siltstone may also contain smectitic clays. The igneous rock fragments include four acid types, one intermediate type and one basic type; these all contain some mica, and are of low porosity with some evidence of mineral alteration. Most of the rock fragments contain zircon and monazite as accessory minerals. One of the acid igneous rock fragments contains a widespread U-rich mineral. The intermediate igneous rock fragment has a trace mineral containing Y, Th, REE and U, and U is detectable in trace amounts in Fe-rich mineral alteration products. The presence of mica group minerals in some form (illitic clays, muscovite, biotite and sericite) in all of the rock fragment samples means that the model proposed above for Cs sorption would also apply to these samples, although some naturally occurring radioactive minerals are also present in most. Rock fragment samples carry a moderate to high risk of further fragmentation; this is illustrated by the fact that two samples have already fragmented and others have relatively fresh chips and faces.

4.6.2.3 Anthropogenic Graphite (1 find)

The graphite particle has a patchy surface deposit containing U with associated Al and Ti. It also hosts micro-particles containing the element pairs Pu-U and U-Zr. Graphite is a very soft material, so dispersal in the environment is possible through contact transfer; microfractures and a strongly developed cleavage suggests fragmentation is also a risk.

4.6.2.4 Anthropogenic Zirconium-rich (2 finds)

One is a pitted angular flake with a Zr-rich substrate that contains irregular U-bearing patches at a 50 micron scale. Cs is detectable in trace amounts, at some analysis points with trace Ba. Sn / Am is also present. The thin and pitted nature of the particle means that it poses a high risk of fragmentation.

The other find is a fractured angular flake with a smooth outer texture. The fracturing has exposed a finely granular inner texture at a 10 mm scale. At the smooth surface, only Zr, O, Al, Fe and Sn are detectable. Minor U is detectable from the granular inner, Cs is patchily detectable in trace amounts and, at some Cs-bearing sites, trace Ba is also detectable. The already fractured nature of the particle suggests that it poses a high risk of fragmentation.

4.6.2.5 Anthropogenic Pu-bearing (1 find)

This sample is present as multiple fragments that come from a single original particle. This has a composition comprising Fe, Ca and P. The original particle had a core of this material that also contains Pu. Np and U are also present. Its presence in multiple fragments and easy further breaking during mounting show that this material is highly prone to fragmentation.

4.6.3 Radionuclide activity in ESR 199 finds

Details of the radionuclide activities are given in Table 11. The table has been arranged in descending order of total beta values. As expected, for the beta-rich finds, the activities of the beta emitters present, principally ^{137}Cs and ^{90}Sr with a smaller contribution from ^{241}Pu, are significantly greater than the alpha-emitting radionuclides reported (^{234,238}U, ^{238,239,240}Pu, ^{241}Am) in those finds. Similarly, for the alpha-rich find, activity of the alpha-emitters ^{238}Pu, ^{239,240}Pu and ^{241}Am are much greater than the beta-emitting ^{90}Sr and ^{137}Cs. Actinides are analysed in beta-rich finds where their presence has been previously indicated by HRGS (*e.g.* ^{241}Am) or EDX analysis (*e.g.* U, Pu, Am).

The highest total beta and ^{137}Cs activities (1.35E+05 and 1.16E+05 Bq respectively) were associated with a ‘Rock fragment’ object from the Sellafield beach whereas the highest ^{90}Sr activity (1.03E+04 Bq) was associated with a ‘Graphite’ particle from Sellafield beach. This ‘Graphite’ particle also contained 1.63E+04 Bq of ^{137}Cs.

The highest activity of ^{238}Pu (3.85E+04 Bq), ^{239,240}Pu (5.0E+04 Bq) and ^{241}Am (9.35E+04 Bq) was found in a ‘Pu-bearing’ particle from Allonby beach.

The seven highest total beta and ^{137}Cs activities are actually associated with 'objects' (first seven entries of Table 11, finds > 2 mm) rather than 'particles'. These observations were only confirmed once the finds had been isolated in the laboratory. The units in Table 11 are Bq per find rather than Bq per unit mass, hence the observation that relatively larger objects can contain higher levels of activity than relatively smaller particles. These seven objects range from 4.0 to 15 mm in size.

Ignoring the 'Object' data in Table 11, the highest total beta and ^{137}Cs activities would be 4.21E+04 and 3.59E+04 Bq respectively. These activities were associated with a 'Graphite' and a 'Biotite mica' particle respectively, both from Sellafield beach.

Comparison of the two Allonby beach particles shows that their physical characteristics are totally unrelated. The alpha-rich particle is of anthropogenic origin (Pu-bearing) with plutonium and americium present whereas the beta-rich particle is a naturally occurring rock fragment with only ^{137}Cs present. This difference in characteristics has been observed in many previous analyses of alpha-rich and beta-rich particles from the same area since 2009.

4.6.4 $^{137}Cs/^{90}Sr$ ratios in ESR 199 finds

Knowing what the $^{137}Cs/^{90}Sr$ activity ratio is of a beach find is an important parameter for calculating radiological doses. Caesium-137 can be determined relatively easily and non-destructively via HRGS whereas determination of ^{90}Sr activity is more resource demanding and time consuming. If a reliable relationship can be determined between ^{137}Cs and ^{90}Sr then an estimate can be made of the ^{90}Sr activity of a find based on the ^{137}Cs activity.

The lowest $^{137}Cs/^{90}Sr$ activity ratio measured in the finds analysed in 2016/17 was 1.6 in a graphite particle (Table 12). This is higher than the $^{137}Cs/^{90}Sr$ activity ratio of 0.61 adopted by Brown & Etherington (2011) in their risk assessment of beach finds and would suggest that the risk assessment predicted higher doses than would be determined from the current measurement data.

The ^{90}Sr and ^{137}Cs activities in the LSN 1356458 graphitic particle are consistent with the relationship presented in Figure 19 (inset) where the linear relationship between all particles with ^{90}Sr activities over 3000 Bq and their corresponding ^{137}Cs activities is shown (see also Table 13 for further particle details). These data points are related to relatively low $^{137}Cs/^{90}Sr$ activity ratios (1.3 – 1.6), have similar dimension (around 1 mm) and all are either graphitic or metallic in nature. The larger plot in Figure 19 shows the spread of all beach finds analysed since 2013, where ^{90}Sr and ^{137}Cs concentrations have been reported.

A recent review (Golder, 2016c) identified the mica group minerals as having a particular affinity for Cs sorption. This is because micas have interlayer sites that the Cs^{+} ion is an 'exact fit' for. Once the Cs^{+} is adsorbed in these sites in the mica structure, it is relatively stable and unlikely to be displaced by other common cations. The mica content of stones is therefore considered to be a major constraint on Cs adsorption potential. Some of the rock types identified in the Sellafield region show evidence of mica. Strontium does not show the preferential sorption behaviour described above for Cs with respect to micaceous sediments and rocks. This is a consequence of its much smaller ionic size. From Table 11 and Table 12, the anthropogenic graphite particle has a ^{137}Cs: ^{90}Sr ratio of 1.6, the anthropogenic Zr-rich particles have ^{137}Cs: ^{90}Sr ratios between 26 to 160 and the naturally occurring biotite micas and rock fragment objects have ^{137}Cs: ^{90}Sr ratios between 430 and 3500. From this it is evident that on the shoreline in the vicinity of the Sellafield site, ^{137}Cs and ^{90}Sr are present in similar magnitudes in graphitic particles whereas in mica minerals and mica-containing rocks, ^{137}Cs is present at orders of magnitude greater than ^{90}Sr.

Table 11: Radiochemical analysis of ESR199 beta rich finds (Bq per find).

Sample Code No.	Area	Petrographic Category	Total Beta	^{90}Sr	^{137}Cs	^{241}Pu	Total Alpha	^{234}U	^{238}U	^{238}Pu	$^{239,240}Pu$	^{241}Am
2120530 (O)	Sellafield	Rock Fragment (N)	135000	80	116000	80	<500	NA	NA	9.9	22	188
2123981(O)	Sellafield	Rock Fragment (N)	122000	125	107000	NA	<500	NA	NA	NA	NA	NA
2037993(O)	Sellafield	Rock fragment (N)	101000	195	84500	NA	517	NA	NA	NA	NA	NA
2019088(O)	Sellafield	Rock fragment (N)	97900	107	87800	NA	<500	NA	NA	NA	NA	NA
2105862(O)	Sellafield	Rock fragment (N)	93700	68	82600	NA	565	0.066	0.059	NA	NA	NA
1133608(O)	Sellafield	Rock fragment (N)	68800	68	62800	NA	<500	NA	NA	NA	NA	NA
1428285(O)	Sellafield	Rock fragment (N)	66600	37	60800	414	480	NA	NA	44.2	239	169
1356458	Sellafield	Graphite (A)	42100	10300	16300	50	351	0.067	0.059	10.7	108	111
1142864	Sellafield	Biotite mica (N)	40700	26	35900	NA	199	NA	NA	NA	NA	NA
1188757(O)	Sellafield	Rock fragment (N)	40400	12	36000	68	NA	NA	NA	9.7	31.8	79
1135557(O)	Sellafield	Rock fragment (N)	24200	7.6	25900	NA	98	NA	NA	NA	NA	NA
1198194	Sellafield	Zr-rich (A)	23900	141	21900	<3	139	0.092	0.06	2.16	9.66	23.4
1192904(O)	Sellafield	Rock fragment (N)	21200	14	19700	NA	190	NA	NA	NA	NA	NA
1207889	Sellafield	Biotite mica (N)	18900	4.7	16400	NA	<200	NA	NA	NA	NA	NA
1135201	Sellafield	Rock fragment (N)	14400	<8.1	13400	NA	90	NA	NA	NA	NA	NA
1195597	Seascale	Zr-rich (A)	13700	450	11500	NA	40	0.035	0.028	NA	NA	NA
1517282	Allonby	Pu-bearing (A)	11000	NA	3.95	NA	150000	90	32	38500	50000	93500
1209722	Sellafield	Biotite mica (N)	10400	7.3	9400	NA	<100	NA	NA	NA	NA	NA
2017913	Allonby	Rock fragment (N)	7800	<8.3	7830	NA	102	NA	NA	NA	NA	NA

(A) – Anthropogenic; (N) – Natural; (NA) - Not Analysed; (O) – Object > 2mm

Table 12: Cs/Sr activity ratios and summary of dose rate measurements mSv h^{-1}.

Sellafield LSN	Area	Description	^{137}Cs / ^{90}Sr Ratio	EXTRAD TLD	Radiochromic Dye Film	Ion Chamber IC 23344W	Average Dose Rate
1207889	Sellafield	Particle	3500	15.3± 1.5	9.9± 3.8	7.5± 0.3	10.9
1135557	Sellafield	Object	3400	14± 1	10.3± 4.5	6.5± 0.5	10.3
1188757	Sellafield	Object	2900	18.2± 1.8	9± 1.5	8.2± 0.3	11.8
1428285	Sellafield	Object	1700	11.6± 1.2	10.2± 2.1	6.3± 0.3	9.37
1135201	Sellafield	Particle	1700	9.8± 0.9	5.3± 5	5.9± 0.4	7.00
2120530	Sellafield	Object	1500	14.4 ± 1.4	11± 1.5	9.3± 0.3	11.6
1142864	Sellafield	Object	1400	28± 3	12± 2	18± 1	19.3
1192904	Sellafield	Particle	1400	16± 2	6.3± 1.3	7.8± 0.5	10.0
1209722	Sellafield	Particle	1300	1.31± 1.3	5.5± 0.5	5.5± 0.2	4.10
2105862	Sellafield	Object	1200	3.8 ± 0.4	4± 1.3	4.2± 0.3	4.00
2017913	Allonby	Particle	940	6.6± 0.6	2.8± 0.9	2.3± 0.2	3.90
1133608	Sellafield	Object	920	5.3± 0.5	4.9± 1.2	4.1± 0.1	4.77
2123981	Sellafield	Object	860	5.7 ± 0.2	5.9± 1.1	5.2± 0.2	5.60
2019088	Sellafield	Object	820	2.3 ± 0.2	3.1± 0.4	2.9± 0.1	2.77
2037993	Sellafield	Object	430	6.6 ± 0.6	3.7± 3.4	5.2± 0.4	5.17
1198194	Sellafield	Particle	160	49± 5	12± 2	16± 1	25.7
1195597	Seascale	Particle	26	21.9± 2.2	11.7± 3.8	9.2± 0.4	14.3
1356458	Sellafield	Particle	1.6	55± 5	28± 5	30± 2	37.7
1517282	Allonby	Particle	NA	0.2± 0.02	0.3± 1.7	0	0.17

NA – ^{90}Sr not analysed due to it being alpha-rich

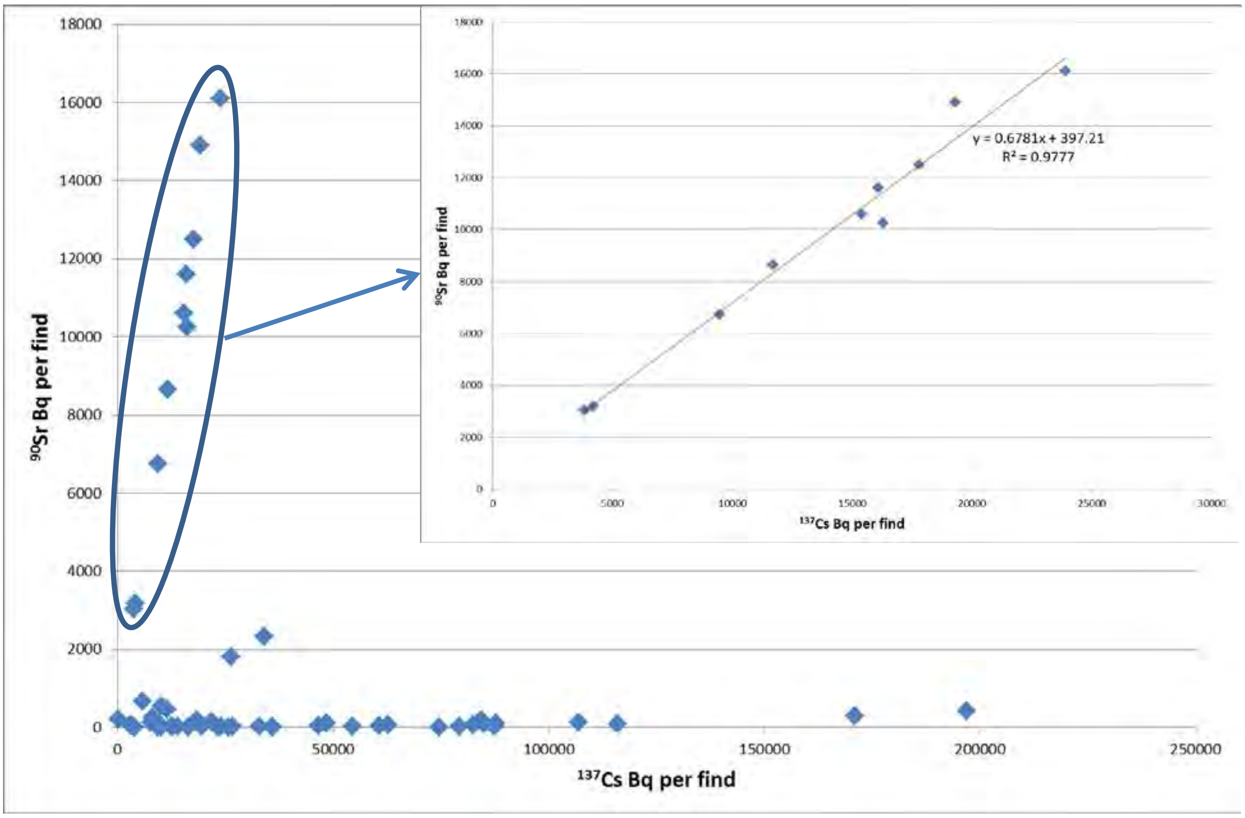


Figure 19: Comparison of ^{90}Sr and ^{137}Cs activities in further analysed beta rich beach finds. Inset - ^{90}Sr activities greater than 3000 Bq per find.

Table 13: Details of all analysed particles which have ^{90}Sr greater than 3000 Bq per find.

Further Analysis Description	Sellafield LSN	Date of Find	Sr-90	Cs-137	Cs/Sr ratio	Matrix
ESR162 Second Batch	1240199	20/07/2009	16100	23900	1.48	Zirconium
ESR162 First Batch	1329902	15/11/2010	14900	19300	1.30	Graphite
ESR162 Second Batch	1187688	15/09/2008	12500	17800	1.42	Zirconium
ESR162 Second Batch	1446565	29/10/2012	11600	16100	1.39	Metal
ESR162 Second Batch	1198034	09/12/2008	10600	15400	1.45	Graphite
ESR199 May Batch	1356458	09/05/2011	10250	16300	1.59	Graphite
ESR162 Fourth Batch	1150055	13/02/2008	8650	11700	1.35	Graphite
ESR162 Second Batch	1493957	05/09/2013	6740	9470	1.41	Metal
ESR162 Second Batch	1493956	05/09/2013	3180	4200	1.32	Metal
ESR162 First Batch	1249081	27/08/2009	3040	3840	1.26	Graphite

Note: Table does not include the S1164/SEA particle recovered on Seascale beach.

4.6.5 Skin contact dose rate measurements.

Skin contact dose rate measurements of beach finds have been developed since 2015 by PHE (Tanner *et al*., 2017a; Tanner *et al*., 2017b; Eakins *et al*., 2017). Three techniques have been applied to the beach finds selected for further analysis during 2016/17. These are thermoluminescent detectors (TLDs), radiochromic dye film and a small ionisation chamber.

4.6.5.1 Thermoluminescent Detectors

Extremity thermoluminescence dosemeters (EXTRAD TLDs) are standard issue for personal dosimetry. In applying to beach finds, the TLD was removed from its usual holder so that the find could be located more accurately over the sensitive LiF:Mg,Cu,P element of the TLD. A transparent polyethylene terephthalate (PET) film was used as a filter between the find and the element, with a thickness (50 μm) that was approximately equivalent to a depth of 70 μm of tissue in terms of mass-thickness.

4.6.5.2 Radiochromic Film

Radiochromic dye film is a radiosensitive material that darkens on exposure to ionising radiation. It is typically used to aid radiotherapy setup. The type of radiochromic dye film used in the measurements was a custom version of Gafchromic® EBT3 film, which comprised of a 125 μm thick clear polyester backing layer and a 15 μm thick active layer. The standard EBT3 film routinely supplied had a thick protective layer that would make it useless for skin dosimetry application. The customised material was supplied with the protective layer removed. The application of radiochromic film to determine skin contact dose rates from beach particles is at a developmental stage and is not a robust technique relative to the use of TLDs or ionisation chambers.

The radiochromic dye film samples were evaluated using Photoshop™ using the area selection feature and assessed using the red channel transmission levels over a 1 cm x 1 cm area centred on the region of greatest film darkening. Dose estimation relied on relating the darkening of the exposed film to the dose applied: higher doses result in darker film, but the relationship is not linear therefore a calibration curve was established and applied.

4.6.5.3 Ionisation Chambers

Measurements were performed using a PTW Unidos E electrometer connected to a PTW 23344W ionisation chamber, with a volume of 0.2 cm^3. A PET film of 23 μm thickness was placed before the entry window as this combination provides a mass-thickness that is similar to human skin. Correction factors needed to be derived and applied for this technique.

4.6.5.4 Skin contact dose rate results

A summary of the mean skin contact dose rate measurement results for ESR199 samples are presented in Table 12. The dose rates assessed were in terms of $H_p(0.07)$ averaged over 1 cm^2, with units of mSv h^{-1}. This is taken as an adequate estimator of the dose to skin averaged over the most exposed 1 cm^2, for a skin depth 50 – 100 μm, which has the units of mGy h^{-1}.

The measured skin contact dose rates are very low, with the highest being 55 mSv h^{-1} (55 mGy h^{-1}) for LSN1356458 using EXTRAD TLD. This is well below 300 mGy h^{-1}, the dose rate at which PHE advises that an urgent review of health risk is required.

PHE are currently considering which of the three methods used in the determination of skin contact dose rates is the optimum technique to be taken forward.

4.6.5.5 Measured versus calculated skin contact dose rate results

Measurements of the skin contact dose rate of ESR162 and ESR199 beach finds by PHE (average of the three methods employed) have been compared to calculated skin contact dose rates using the conversion factors derived by the University of Birmingham (Serco, 2011). The dose conversion factors derived were 1.8 Gy hr^{-1} per MBq for ^{137}Cs and 4.6 Gy hr^{-1} per MBq for ^{90}Sr. These factors were derived as a dose screening measure. It should be noted that an absorbed dose of 1 Gy is the same as an equivalent (tissue) dose of 1 Sv when considering beta radiation; hence the units of Gy and Sv are interchangeable in this context.

There are 24 beach finds in total that have had positive ^{90}Sr and ^{137}Cs measurements reported and skin contact dose rate measurements made by PHE. Initial comparisons showed that at relatively lower doses, <25 mSv h^{-1}, agreement between measured and calculated dose values was poor. This was not unexpected as the dose conversion factors were derived with the intent of screening the more active beach finds. Comparison of measured skin contact dose rates against calculated dose rates, above 25 mSv h^{-1} show a very good relationship (Figure 20). The plot shows that the calculated dose rates are conservative as many of the points lie above the 1:1 relationship line. The relationship shown in Figure 20 supports the use of the dose conversion factors in deriving skin contact dose rates for beach finds prior to any direct measurements being made.

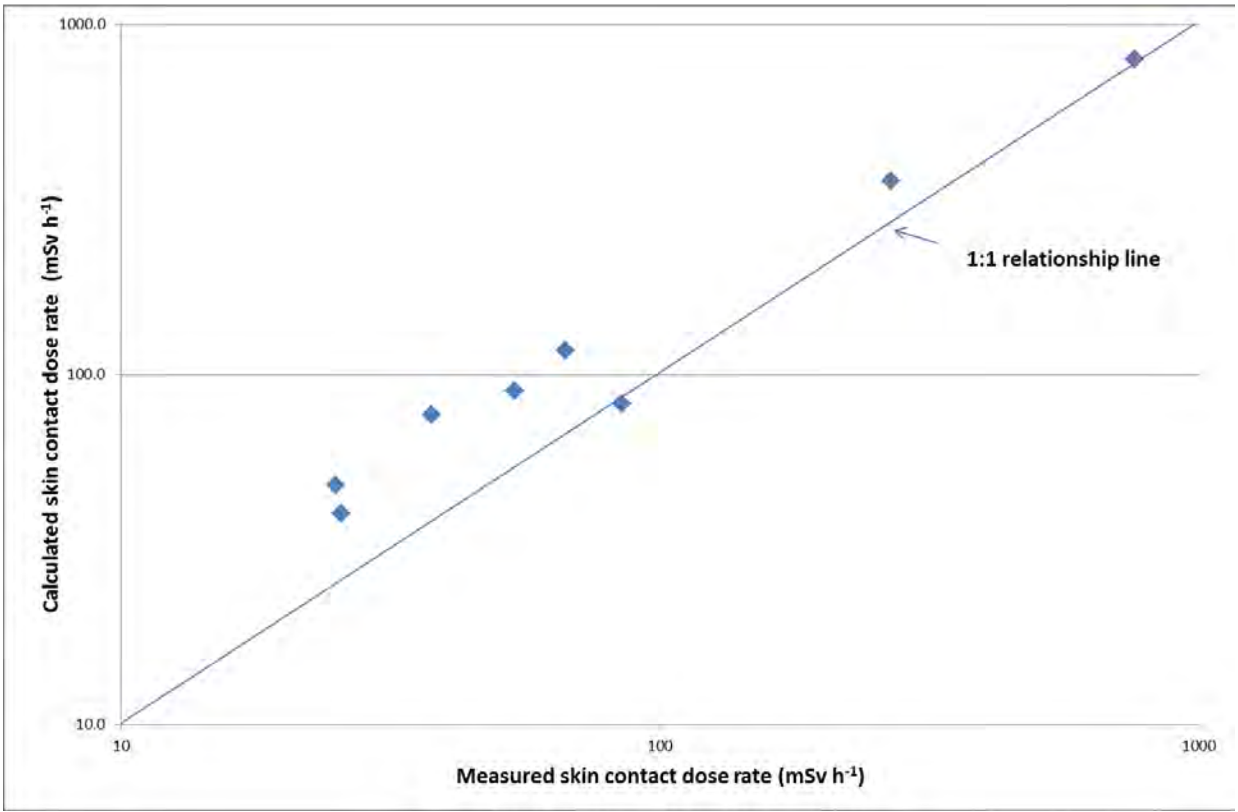


Figure 20: Comparison of measured and calculated skin contact dose rates (> 25 mSv h^{-1}).

4.6.6 Summary of further analysis of beta-rich finds 2009 – 2017

Since 2009 over 200 beach finds have been identified for further analysis. Analysis and discussion of further analysed alpha-rich finds was presented in the 2014 *Particles in the Environment* report (Sellafield Ltd, 2014a). A clear relationship between alpha activity with iron/iron oxide material was described. Here a summary of the beta-rich finds that have been further analysed is given (with the exception of particle S1164/SEA which was discussed at length in last year's report (Sellafield Ltd, 2016)).

The major radionuclide contributors to beta activity in beach finds are from ^{90}Sr and ^{137}Cs. Caesium-137 is relatively easily quantified through non-destructive HRGS whilst ^{90}Sr is quantified through destructive radiochemical analysis of the find (Table 10). There were 88 finds from which there were positive values for both ^{90}Sr and ^{137}Cs in the same find. It is from this set of finds that the following observations have been made.

The dominant matrix types of the Sr/Cs-containing beta-rich finds is 'Rock' followed by 'Graphite' and 'Metal/Zr-rich' (Figure 21). There are five matrices of interest for the beta-rich finds (Figure 21) compared to only one for the alpha-rich finds (Iron/ Iron oxide).

The 'Rock' finds consist of 25 objects and 7 particles. The eleven highest ^{137}Cs activities in all of the beta-rich finds are associated with 'Rock' objects (6.28E+04 – 1.71E+05 Bq per find). The ^{90}Sr activities in these eleven objects are much lower and range from 8.0E+00 to 1.1E+03 Bq per find resulting in high Cs/Sr ratios of 430 to 9000.

The 'Graphite' finds are all particles. The four highest ^{90}Sr activities are associated with 'Graphite' particles (1.47E+04 - 4.89E+04 Bq per find). Indeed, eleven of the 14 highest ^{90}Sr activities are associated with 'Graphite' particles. The ^{137}Cs activities in these 14 particles range from 3.84E+03 to 6.0E+04 Bq per find, relatively low compared to the maximum ^{137}Cs activities recorded. The Cs/Sr ratios are subsequently low, ranging from 0.66 to 2.94.

The 'Metal/Zr-rich' finds are all particles. The ^{90}Sr activities range from 2.9E+01 to 2.3E+03 Bq per find and ^{137}Cs activities range from 2.8E+02 to 5.4E+04 Bq per find. The Cs/Sr ratios range from 29 to 2320.

The 'Biotite mica' finds are all particles. The ^{90}Sr activities are relatively low and range from 1.6E+00 to 1.9E+02 Bq per find. The ^{137}Cs activities range from 4.0E+03 to 3.6E+04 Bq per find. The Cs/Sr ratios range from 96 to 3490. These observations are consistent with the ^{90}Sr and ^{137}Cs binding characteristics given in Section 4.6.4.

The 'Iron/Iron oxide' finds are a mixture of particles and objects. The ^{90}Sr activities range from 3.0E+00 to 3.8E+03 Bq per find and ^{137}Cs activities range from 5.0E+00 to 6.2E+04 Bq per find. The Cs/Sr ratios range from 1.1 to 3900.

In summary, Beta-Rich finds with a:

- ^{137}Cs activity in the order of 1.0E+04 Bq or greater and are graphitic in nature will tend to have a ^{90}Sr activity greater than 3.0E+03 Bq;
- ^{137}Cs activity in the order of 6.0E+04 or greater and are rock based in nature will tend to have a low ^{90}Sr activity of less than 1.0E+03 Bq; and,
- ^{137}Cs activity in the order of 4.0E+03 or greater and are mica in nature will tend to have a low ^{90}Sr activity of less than 2.0E+02 Bq.

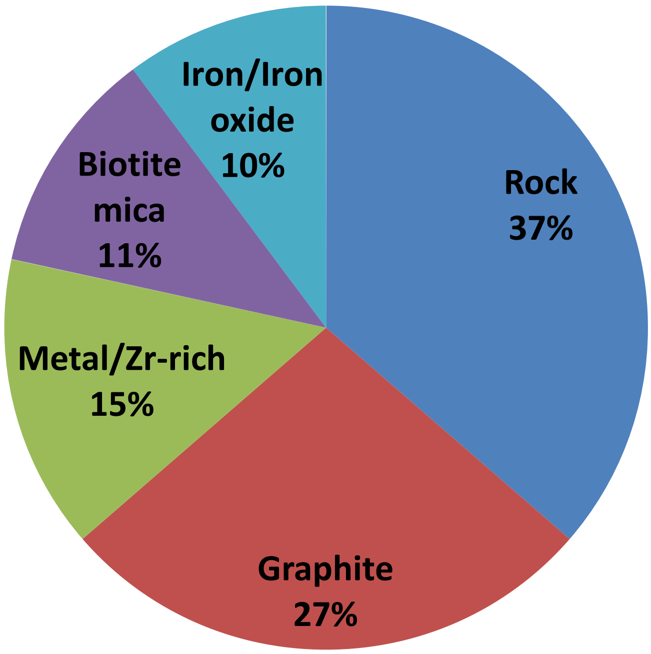


Figure 21: Matrix type distribution for ^{90}Sr and ^{137}Cs- containing beta-rich finds.

4.7 Beach Monitoring Programme Conclusions

The 2016/17 beach monitoring programme was successfully completed to schedule. A total of 166.7 hectares, between Allonby and Drigg point, was monitored and 254 radioactive finds recovered. The number of finds detected decreased for most beaches when compared with the previous year and find rates were all below the peak Synergy 2 levels.

A total of 87.9 ha of beach were monitored at Sellafield beach in 2016/17, providing reassurance that the find rates and find characteristics on the beach with the highest historic find rates had not changed significantly. The monitoring at Braystones, St. Bees and Seascale totalled 67.0 ha, providing reassurance that find rates on beaches with high public occupancy remain low. The remaining monitoring effort was deployed on far-field beaches, in particular Allonby beach, with 10.7 ha of monitoring completed at this location.

The types of material being recovered during 2016/17 remained consistent with those retrieved since commencement of the monitoring programme. The distribution of ^{137}Cs and ^{241}Am activities of current particles remain within observed ranges of all particles to date, providing reassurance that they are part of the same general population. This provides further evidence that the conclusion of the PHE risk assessment in 2011 remains valid and are as follows.

"The conclusion, based on the currently available information, is that the overall health risks to beach users are very low and significantly lower than other risks that people accept when using the beaches." (Brown & Etherington, 2011)

5 Assessment of Best Available Technique (BAT)

5.1 Particles in the Environment BAT/ Optioneering

A large amount of work has been done over recent years to improve understanding of both the beach and the marine environments and the implications on transport and dispersion of radioactive particles. For sub-sea, limited modelling work, data gathering and interpretation (*e.g.* swath bathymetry and Aquadopp deployment reported in Sellafield Ltd, 2011) and desk-based options assessment have all contributed, but the information being gathered from the beach monitoring provides the richest data source on the particles issue. Each year the level of understanding on particles in the environment increases as beach monitoring continues to reveal information on find populations, locations, activity concentrations, *etc.*

A BAT case was submitted to the EA at the end of May 2013 (Sellafield Ltd, 2013) and the EA responded in the form of a Radioactive Substance Compliance Assessment Report (RASCAR) at the end of August 2013. A revised BAT assessment was produced and submitted to the EA in 2014 (Sellafield Ltd, 2014b) that updated the previous work. The EA provided a response to the updated BAT case in November 2014. The BAT case (Sellafield Ltd, 2014b) determined that the techniques shown in Table 14 could be deployed for detecting the types of radioactive materials found on West Cumbrian beaches with the NaI detectors that are currently used representing the optimal technique.

Table 14: Techniques for detecting radioactive particles on the beaches.

Method		Discussion Summary
Alpha	Detection of alpha emitters using X-Ray and low energy gamma radiation – NaI	Well established and practicable technique for low energy gamma/X-Ray detection. Good area coverage. Can be utilised within a vehicle or hand held assembly.
	HpGe detectors for X-Ray emissions	Well established and practicable technique for low energy gamma/X-Ray detection in the lab and successfully trialled on beach environment. This technique gives good area coverage and can now be mechanically chilled in the field.
Beta	Plastic Scintillation Detectors	Well understood, off the shelf technique requiring only minimal modification to enable practical use in the beach environment. Vehicle and hand-held use practicable.
Gamma	NaI Scintillation Detector	Current technique used for beach monitoring at Sellafield. Well established and versatile technique, good detection efficiency, good area coverage, tough and relatively simple to use. Can be utilised for hand held or vehicle use.
	High Purity Germanium Detector (HpGe)	Optimum energy resolution, well established technique, now mechanically chilled, but more expensive than NaI Scintillation Detectors.

The detection of material on the seabed was also considered in the BAT case (Sellafield Ltd, 2014b) although no optimal technique could be identified that would meet the criteria of detecting and recovering both alpha rich and beta rich particles on the seabed, that would provide reasonable area coverage and would not be disproportionately expensive. The study considered that grab sampling provided the best compromise between the above criteria and further sampling was conducted in 2014 and reported in Sellafield Ltd (2015). This work provided a considerable amount of data on the characteristics of the seabed and of bulk radionuclide concentrations. Although, from 1706 successful grab samples (retrieved between August 2011 and August 2014 from 6 extensive campaigns of sampling) an area of approximately 170.6 m^2 of seabed was monitored yielding a single particle (in April 2012).

A similar level of resource deployment to the areas of peak find rates on the beaches would have been likely to have detected several hundred particles and objects. In addition, there are significant Health and Safety Risks associated with offshore work and therefore grab sampling has been discontinued, allowing the programme to concentrate on beach monitoring.

5.2 Progress in meeting the 2014 BAT recommendations

A list of the recommendations of the 2014 BAT case, the responses from the EA and the progress in addressing the recommendations is shown in Table 15. The evaluation of BAT is an ongoing process, as technologies are developed and evaluated that have the potential to be used for the detection of beach and/or seabed particles.

Work during 2016/17 has focused on the following specific areas:

- Review of coastal geomorphology (Section 5.2.1).
- Trial of an unmanned aerial vehicle for photographic surveys (Section 5.2.2).
- Development of a forward monitoring strategy through the Sellafield Particles Working Group (Section 8.4).
- Further laboratory analysis and characterisation of particle finds (Section 4.7).

Table 15: 2014 BAT case recommendations, responses from the EA and progress.

BAT Recommendation	EA Response	Progress
1. Continue the current beach monitoring approach as agreed with the Environment Agency.	Agreed.	Ongoing and part of the routine programme.
2. Conduct a review of the performance of the Synergy 2 monitoring system after an appropriate period (anticipated to be 12 months). In particular this review should evaluate the performance of the system for the detection of ^{90}Sr.	Agreed.	Completed and reported in 2015/16.
3. Continue seabed sediment grab sampling, as carried out in 2011, 2012, and 2013 although evaluate the use of a larger grab sampler and methods to improve the sampling efficiency to increase the number of samples collected per day. The seabed monitoring campaigns should also focus on areas that were indicated by the Conceptual Site Model to have higher potential find rates.	Should consider ways to delineate the area of offshore contamination.	Completed and reported in 2014/15.
4. Maintain a watching brief on monitoring methods for beach particles (in particular for ^{90}Sr) and for seabed particles (in particular crawler ROVs and the seabed detection of alpha rich material).	May need to include the development of alpha (americium) detection capability through lab trials of sodium iodide detectors.	Ongoing, details provided in 2016/17. (Sellafield Ltd, 2016).
5. Consider the feasibility of conducting further beach trials to evaluate the performance of Synergy 2 for detecting ^{90}Sr.	Should be to undertake laboratory trials and then develop a case for any beach trial following this.	Completed and reported in 2015/16.
6. Align the walked surveys of the coast so that the Nuvia team carrying the large volume NaI detector and the Sellafield team carrying the FIDLER probe cover the same area on the same days.	Agreed.	Completed.
7. Modify the beach sampling programme to redeploy 10 ha of monitoring effort from beaches with the lowest risk (Drigg and Northern beaches) to Braystones.	Agreed.	Completed.
8. Develop a forward monitoring strategy that included exit strategy options.	Should be through consultation with the Sellafield Particles Working Group, COMARE, WCSSG and Copeland Borough Council.	Completed and reported in 2015/16.

BAT Recommendation	EA Response	Progress
9. Continue ^{90}Sr analysis of objects with the selection of samples based on ^{137}Cs activity and contact dose rate.	Agreed.	See Section 4.6.3.
10. Continue statistical work to underpin the monitoring programmes and sampling arrangements for both the beach and sub-sea environments.	Agreed.	Ongoing, see Section 4.
11. Maintain a watching brief on marine modelling methods and the possibilities for adjacencies with the programmes for other infrastructure developments.	Should be guided by a review of the information needs for any modelling work. The forward programme should then consider an appropriate priority for the filling of each of these and ensure that maximum value is obtained from other work done such that the need for additional 'model input specific' work is limited.	Ongoing, see Sections 5.2.1 and 6.4.
12. Evaluate the influence of standing water on the detection efficiency of Groundhog Synergy 2.	Agreed.	Completed and reported in 2015/16.
13. Develop a formal contingency plan to deal with issues including equipment failure or obsolescence and provide a basis for decision making that avoids the threat of failing to meet the agreed programme.	Agreed.	Completed.

5.2.1 Review of coastal geomorphology

A review of coastal geomorphology and sediment transport was undertaken by Golder Associates working with CH2M Hill and Eden NE (Golder, 2016d). The review considered the following topics (detailed in the remainder of this section).

- Coastal processes related to the transport of particles and objects (see Table 16, overleaf, for a summary of the reviewed information).
- Review of rocky foreshore areas.
- Sediment sinks on dunes.
- Review of data on the concentrations of radioactivity in bulk sediments.
- Review of methods for monitoring beach height.
- Review of modelling packages.

Table 16: Review of Coastal Processes.

	Calm conditions	**Storm conditions outside surf zone**	**Storm conditions within surf zone**
Water and sediment transport direction in the vicinity of the pipeline	Flow is towards NW near high water and towards SE near low water. Sediment transport is in the same direction as flow during periods when the bed shear stress exceeds the minimum value for sediment motion.	Current monitoring data offshore of the site shows that the effect of storm winds (and storm surge) can increase the current speeds and cause currents to persist in one direction over several tides (2 days). Strong SW winds induce flow towards N while NE winds induce flow towards S.	It is expected that the flow and sediment transport in the surf zone is due to combined tide and wave driven currents. As the shoreline faces almost normal to the dominant SW wave direction, individual storm waves can generate longshore currents towards the N and S depending on the wave direction. Previous longshore sediment transport results show that the net direction along the frontage is generally northwards. Furthermore, tidal flow is northwards near high water, and SW winds cause flow towards the north, these processes are likely to increase the N longshore currents and reduce S longshore currents for southerly storms.
Strength of main forcing terms and frequency	Relatively weak tidal currents (< 0.6m/s) over every tidal cycle. The calculated peak bed shear stress is 0.2 to 0.4 N m^{-2}.	Peak flows during a storm event is approximately 0.9 to 1.0 m s^{-1} around high water. Available (long term) wind records from the study area shows that winds occur more frequently from S sectors than N sectors. The strongest winds also tend to have a S component.	No information is available in the reviewed literature on the strength of the combined wave and tidal currents within the surf zone.
Predicted effect on particle / object transport	The minimum bed shear stress required to move objects (D > 2mm) is 1.25 N m^{-2}, while the minimum shear stress for D=0.2mm is 0.17 N m^{-2}, and 0.38 N m^{-2} for D=0.8mm. Thus, tidal current at this site is not strong enough to move sediment with diameter of 2mm or larger. However, sediment finer than 0.2mm to 0.8mm can be mobilised occasionally during the tidal cycle. Tidal currents are directed towards the NW near high water, so particles located above low tide level are subject to potential net northward transport.	During storm conditions the effect of wind and waves are important contributors to the sediment transport. The maximum bed shear stress in combined waves and currents in the vicinity of the pipeline outlet is calculated to exceed 1.25 N m^{-2} when wave height exceed 1.0m and current speed of 0.3 m s^{-1}. Thus, fine particles and objects in the vicinity of the pipeline outlet will move (in the direction of the flow) when these conditions are exceeded. Wave heights exceeding 1.0m from the southern sectors are expected to occur about 20% of the time.	The net potential longshore transport is generally northwards along the study frontage, but the direction can be variable near Sellafield. As the shoreline faces almost normal to the dominant south westerly wave direction, the net annual transport is small compared to the gross north and south directed transport components. This provides a mechanism to disperse particles to the north or south in the surf zone.
Conclusion **(Assumes pipeline is the main historical source)**	It is unlikely that tidal currents alone are responsible for the movement of particles and objects to the beaches	Storm conditions are likely to be responsible for northward transport of particles (and possibly objects) in the vicinity of the pipeline outlet due to the predominance of southerly winds and waves at the site.	Storm conditions are likely to be responsible for net northward transport of particles (and possibly objects) in the vicinity of the pipeline due to the predominance of southerly winds and waves at the site. However, the effect of combined tides and waves in the surf zone is yet to be studied in detail.

Review of rocky foreshore areas

The review demonstrated that a variety of shore platform types occur along the west Cumbrian coast, and that the Braystones to Sellafield frontage comprises a cobble shore platform, derived from gradual erosion of the underlying glacial sediments, which is overlain by highly mobile sand and occasionally colonised by the reef-building honeycomb worm *Sabellaria alveolata*.

It was considered very unlikely that radiological material (particles or objects) were present below the surface of the cobble platform because cobbles are tightly packed and do not appear to move, even under typical storm conditions. However, it was considered possible that radiological material was present within the tightly-packed sand and gravel in the interstitial spaces between cobbles, however the high wave energy that the platform is exposed to means it is unlikely that material can accumulate.

Sabellaria reefs are located at several locations on the shore platform and thrive where there is an abundant supply of sand in the water column. It seems likely that reefs have persisted for many tens of years, and probably since original construction of the Sellafield site and it is therefore possible that radiological material has been locked in to reefs.

Sediment sinks on dunes

The review described the processes that lead to formation of barriers, spits and dunes and commented on sedimentary linkages between these features and the adjacent beach and river systems. The principal conclusions were:

- The Ehen valley is fronted by a barrier and spit complex composed of cobbles and gravel that has a capping of dune sand.
- The barrier component was formed many thousands of years ago from coarse sand and gravel-sized sediment derived from the seabed, shore platform and cliffs. It is very unlikely to include any radiological material.
- The spit component, which extends south from the Ehen valley towards Sellafield and the River Calder, formed more recently and is derived from beach material that has been transported alongshore by waves and tidal currents. It is therefore possible that the southernmost part (estimated to be 77m long) could contain radiological particles or objects at a lower concentration than that found on the beach.
- Deposition of the capping of dune sand was probably initiated many thousands of years before present. Historical photos and more recent LiDAR data show no evidence for change in the area of height of dunes, although very low rates of accretion are likely. The total thickness of sand is presently around 1m. While it is possible that radiological material has been transported to the dunes, the total amount will be very small. Most of the dune is well vegetated, but localised disturbance by off-road motorcycles provides an opportunity for material to be re-released into the environment. Radionuclides held in the dunes may also be re-released by erosion of the back of the barrier by river erosion, but likely amounts of radiological material affected will be extremely small.
- Although levels of contamination are very low, it is possible that the southern tip of the spit may be a more significant sediment sink than the dunes.

Review of data on the concentrations of radioactivity in bulk sediments

Details of the sub-sea monitoring of radioactivity in bulk sediments conducted for the Particles in the Environment Programme can be found in the annual report for 2014/15 (Sellafield Ltd, 2015).

Analysis of bulk samples of sediment and seawater from the 1970s and 1980s, all indicate a predominant transport of sediment-bound activity to the north of the Sellafield pipeline. During the period from the mid-1970s to the mid to late 1980s, the discharge signal from Sellafield was strong by comparison to the radionuclides already present in sediment as a result of historical discharges. Reviews of the literature undertaken in the early 1990s indicated that transport of sediment-bound radionuclides was predominantly within the particulate fraction, and hence bulk sediment samples from that period are likely to reflect dispersion due to particulate movement.

The reported finds of particulate activity within sediments from the 1970s and 1980s do not represent the types of particles currently identified from the Cumbrian foreshore and, based on size and activity content, would now be characterised as bulk contamination of sediments. Interpreting analysis of more recently obtained bulk sediment samples becomes increasingly complex, as the discharges from Sellafield are now very low by comparison to the period of peak discharges, and the dominant source for many radionuclides in the Irish Sea is the sediment-bound fraction present as a consequence of past discharges. It is likely that much of the current distribution of Pu, and other strongly sediment bound radionuclides, in sediments in the Irish Sea will be influenced by transport in the water column either as suspended particles or as a result of dissolution and subsequent resorption. For radionuclides, such as ^{241}Am, the overall pattern is even more complex as ingrowth from past discharges of ^{241}Pu is now the dominant source term.

Analysis of recent bulk sediment samples does present some useful information with respect to overall patterns of movement. That is, such samples indicate the broad distribution in the marine environment of radionuclides released from Sellafield. However, recent sediment samples are less useful in determining whether transport is due to movement of bottom sediments, transport in the water column as suspended particles or desorption from sediment near to the pipeline (*i.e.* where activity concentrations are generally highest), with transport in solution and subsequent resorption onto fine sediments. The observed higher activity concentrations in sediments to the north of the pipeline may reflect preferential sorption to fine sediment within the mudbank off the Cumbrian coast. Recognising that the mudbank also extends to the south-east of the pipeline as well as the north-west, the general observation that activity is higher to the north may also reflect the permitted window for discharges from the sea tank, with releases occurring on the ebb tide when the tidal flow is predominantly to the north.

It is noted that neither an expanded programme of sampling and analysis for bulk sediment radionuclide activity concentrations, nor the use of sediment tracers would appear to be justified on the basis of improving understanding of determining sediment transport mechanisms and pathways.

Review of methods for monitoring beach height

Analysis of beach monitoring data covering the St. Bees to Ravenglass coastline since 2002 has shown that beaches comprise a highly mobile veneer of sand over a cobble/gravel shore platform that can be considered static over timescales of tens of years. The thickness of sand over the platform is rarely greater than 0.5 m. The steeper gravel upper beach varies in height by around 1 m.

Assessment of LiDAR monitoring data covering the period 2002 to 2009 shows no net change in the beach volume and instead a redistribution of sediment across the St. Bees to Drigg frontage. This supports the conclusions of the LLWR 2011 Environmental Safety Case that the beach is a closed system with no sedimentary links to adjacent coasts and a very low supply of coarse beach-building material from cliff recession and shore platform lowering.

The current monitoring strategy for the Braystones to Sellafield frontage comprises collection of beach elevation data on an approximately monthly basis as part of the PIE programme. In addition the LLWR undertakes annual site inspections to record beach/cliff activity using fixed point photography, and the Cell 11 Regional Monitoring Strategy (CERMS) undertakes twice-yearly beach profile surveys at a small number of sites and commissions periodic LiDAR surveys of the Cumbria coast.

The accuracy of elevation data collected under the PIE programme is relatively low, around ± 50 mm (Sellafield Ltd, 2015), compared to that derived from LiDAR (better than ± 10 mm), but the frequency of collection is much greater (1 to 2 months, compared to 2 years for LiDAR). The data derived from the PIE programme is also limited in extent, with the sand dunes and cobble platforms excluded. It is therefore recommended that PIE data are not used for wide-area beach height analysis because of the lower accuracy, and limited coverage of variable areal extents.

Analysis of LiDAR data collected periodically under the CERMS programme presents a more accurate and more complete picture of changes in the beach. LiDAR data and analytical reports are available at no charge, a site-specific review and assessment could be considered when new data are available.

Site inspections on a 1 to 2 yearly basis do provide a cost effective method of validating the findings of remote sensing data. Reports commissioned by the LLWR should be reviewed when they become available and cross referenced to findings of LiDAR assessments.

UAVs should be considered for quantitative elevation data for beach and cliff monitoring, the technique would deliver better data than conventional aerial surveys (see Section 5.2.2). The entire area of interest could be surveyed within a day, meaning several surveys could be undertaken each year. Data analysis and interpretation need only be undertaken on an annual basis and would be conducted in parallel with a review of weather data available from the Sellafield site to infer beach response to specific storm events. High resolution aerial imagery would be likely to have a range of other applications, including monitoring changes in *Sabellaria* reefs and tracking the movement of specific cobbles/boulders across the beach face.

Review of modelling packages

Tidal residuals along this frontage are relatively weak and cannot explain the observed distribution of particle finds. Hence, non-tidal forces (surge, wind and waves) are important for understanding the residual flow pattern and the net sediment transport along the frontage.

With the present state of knowledge and technology, it is not considered feasible to construct a process-based model (or system of models) that can include all the relevant processes to predict the tracks of particles released into the marine environment. Even if it is computationally possible, it is considered that the accumulation of errors within the different model components may render the results difficult to interpret and/or of limited value.

5.2.2 Trial of Unmanned Aerial Vehicle Survey

During July 2016, a survey was completed using an Unmanned Aerial Vehicle (UAV) above the beaches in close proximity to the Sellafield site; a snapshot of the beach imagery with the 2016/17 monitoring extent overlain is displayed in Figure 22. The trial was deemed to be successful, with inflight photographs capturing the beach areas at Braystones and Sellafield. UAV technology is developing quickly and further aerial surveys may take place periodically in the future to help further understand the nature and movement of the beach.

Figure 22: UAV survey and monitoring extent of Sellafield Beach.

6 Regulator and Stakeholder Engagement

Throughout all aspects of the work described in this report, Sellafield Ltd seeks to maintain open and effective communication with regulatory bodies and a wide range of other stakeholders. The methods of communication are varied. They include:

- General updates and availability of large amounts of information via the sellafieldsites.com website;
- Attendance at specific meetings; and,
- The production of detailed written documents, such as this report.

The following provides further detail on the main processes for communication and engagement.

6.1 General Engagement with the Environment Agency

The EA specifies the following requirements on Sellafield Ltd for the particles in the environment work scope (EA, 2017):

Permit KP3690SX CEAR *Issue 11* *dated 01/04/2017*

Requirement number 4.2.2 Part 2/v010

12. The Operator shall develop a programme of works, to be agreed with the Environment Agency, that:

- *Focuses on those radioactive particles in the environment that have arisen from Sellafield site operations that represent the greatest risks, so that these can be targeted and the risks to the public and the environment mitigated;*
- *Performs large area beach monitoring to detect and recover targeted radioactive particles, at locations and to a programme that is commensurate with particle numbers, distributions, environmental mobility and rates of encounter;*
- *Selects a proportionate number of recovered particles for detailed analysis, to reduce the uncertainty in the assessment of risk, to improve understanding of on-site sources and pathways, and to enable the further development of optimised detection and analytical methods;*
- *Develops a risk-based approach to assess and determine the best method(s) to detect and recover targeted radioactive particles in the environment;*
- *Develops techniques to characterise the transport and dispersion of Sellafield radioactive particles in the environment;*
- *Is supported by a suitable programme of research and development to ensure that the objectives of the programme continue to be met by the application of Best Practicable Means;*
- *Is supported by a schedule specifying the tasks to be undertaken in the programme and timescales for their completion, including routine reporting on progress, and undertaking periodic review and liaison with the Environment Agency and other relevant organisations;*
- *Establishes a basis on which the end point of the programme can be defined; and*
- *Uses techniques that are consistent with the application of BAT (BPM and BPEO) to achieve this end point.*

The Operator shall provide the Environment Agency with a copy of the programme by 31 March 2010, and thereafter annual updates of the programme by 30 June each subsequent year.

As part of managing the delivery of work against the above specification, Sellafield Ltd and the EA communicate regularly via telephone, email, letter and face-to-face meetings on the full range of aspects associated with this work. Face-to-face meetings are typically held quarterly throughout the year, providing an opportunity for general updates to be provided and for specific items to be discussed, with additional meetings as required. Where a decision point is reached that requires agreement or approval by the EA, Sellafield Ltd will make a formal written proposal before proceeding. In addition, any finds that are defined as unusual are formally reported to the EA (see Section 3.6).

Communications and engagement with the EA is not limited to one-to-one dialogue. Where specific items require (or benefit from) wider discussion and input from others, separate meetings or Working Groups have been held or established (for example the Multi-Agency Workshop and Sellafield Particles Working Group).

Sellafield Ltd is also required to prepare written submissions to the EA. This report forms the annual programme update submission that is referred to in the CEAR specification.

Sellafield Ltd regards the need for effective and constructive communications with the EA on this complex subject as essential and believes the processes employed to achieve this continue to be productive and ensure that good progress continues to be made.

6.2 COMARE

The inaugural meeting of the COMARE Contaminations Working Group was held on the 3rd July 2012. This group has combined the Dounreay and Sellafield working groups and extended its remit to cover wider 'particle' contamination issues, *e.g.* Dalgety Bay. A total of nine meetings have now been held, with the latest in March 2017.

The EA routinely presents a paper on progress at Sellafield, which is well received and gives the committee members an opportunity to ask questions and to make suggestions on the forward work programme. The committee has noted that they were satisfied with the approach being taken by the EA and the progress being made by Sellafield Ltd. As with the previous Sellafield Working Group meetings, these meeting are constructive and provide an opportunity for Sellafield Ltd to listen to and discuss some of the committee’s questions at first hand.

6.3 Sellafield Particles Working Group

The Sellafield Particles Working Group was formed at the start of 2015 and replaces the Seabed Monitoring Working Group. The Group has focused on the risk assessment work that Public Health England (PHE) issued on the Groundhog Evolution2 monitoring results (Brown & Etherington, 2011; Oatway, *et al*., 2011) and the update for the Groundhog Synergy monitoring results (Etherington, et al., 2012). In November 2016, a series of reports on the geomorphology of the Cumbrian coast in the vicinity of the Sellafield site were presented at this working group. Further details of this work can be found in Section 5.2.1.

Additionally, the Group has provided an opportunity to review the draft Sellafield particles forward programme and the Group will remain a key forum for taking this work forward through 2017/18. Further details of the work being carried out on the forward strategy are included in Section 8.4.

6.4 Local Stakeholders

Sellafield Ltd continues to communicate with local stakeholders on the work being done. This includes attendance and provision of information to various group meetings, including the West Cumbria Sites Stakeholder Group and responding to questions raised by individuals. As requested by local stakeholders, Sellafield Ltd is continuing to schedule beach monitoring to avoid the busy tourist times of Easter and the summer school holidays.

Copies of the biannual updates and presentations made to the West Cumbria Sites Stakeholder Group, Environmental Health Sub-Committee are available from their web site as follows.

http://www.wcssg.co.uk/subcommittees/environmental-health-working-group/

7 Health Risk Assessment

The Health Protection Agency became part of Public Health England on 1st April 2013. Public Health England was established to bring together public health specialists from more than 70 organisations into a single public health service. It employs scientists, researchers and public health professionals and has 15 local centres and four regions (north of England, south of England, Midlands and east of England, and London). The headquarters of the 'Centre for Radiation, Chemical and Environmental Hazards' remains at Chilton in Oxfordshire. For the rest of this section the Health Protection Agency will be referenced as work was undertaken before the 1st April 2013.

In the 2010/11 Annual Report, Sellafield Ltd reproduced the Executive Summary from the Health Protection Agency risk assessment (Brown & Etherington, 2011), published in April 2011. That summary includes the following paragraph:

"The conclusion, based on the currently available information, is that the overall health risks to beach users are very low and significantly lower than other risks that people accept when using the beaches. The highest calculated lifetime risks of radiation induced fatal cancer are of the order of one hundred thousand times smaller than the level of risk that the Health and Safety Executive considers to be the upper limit for an acceptable level of risk (1 in a million) for members of the public and workers. It is also very unlikely that deterministic effects such as skin ulceration could occur from encountering an object. The likelihood of members of the public ingesting a radioactive particle from the consumption of seafood and the associated health risks have also been estimated using a conservative scoping approach in consultation with the Food Standards Agency. The risks to local consumers of seafood have again been found to be very low."

The EA asked the Health Protection Agency to review the data from the Synergy detection system and revise their advice accordingly, if needed. The Health Protection Agency completed their review of the Synergy data (Etherington, et al., 2012) in August 2012. They concluded that the statement above was still valid; an extract from the executive summary is given below.

"The conclusions from the earlier HPA study on health risks to members of the public from radioactive objects on the beaches remains unchanged. That is, based on the currently available information, it may be concluded that the overall health risk to beach users are very low and significantly lower than other risks people accept when using the beaches. The highest calculated lifetime risks of radiation-induced fatal cancer are of the order of one hundred thousand times smaller than the level of risk that the Health and safety Executive consider to be the upper limit for an acceptable level of risk (1 in a million) for members of the public and workers. The conclusion that it is very unlikely that deterministic effects such as skin ulceration could occur from encountering an object also remains unchanged."

As part of the work controlled by the Sellafield Particles Working Group, PHE has reviewed the risk assessment for consumption of seafood in the vicinity of Sellafield with respect to the potential for high specific activity particles to be present. The abstract of this report (Oatway & Brown, 2015b) is reproduced below.

"Since 2006 an intensive programme of monitoring for radioactive objects has been carried out on beaches in the vicinity of the Sellafield site in West Cumbria to help assess any potential impacts from on-site activities on the environment and people. These objects comprise particles with sizes smaller than or similar to grains of sand (less than 2 mm) and contaminated pebbles and stones. The health risk to people using the beaches along the Cumbrian coast from contaminated objects on those beaches was previously assessed by Public Health England (PHE), formerly the Health Protection Agency. As part of that assessment, the health risks from contaminated objects that may be ingested via the consumption of locally caught seafood were considered using the results of a conservative scoping study carried out in consultation with the Food Standards Agency.

The Environment Agency (EA) has a work programme to ensure that the overall programme of monitoring, both on the beaches and off-shore, addresses the remaining areas of uncertainty in a prioritised way as well as providing reassurance that the risks remain low. As part of that programme of work, EA commissioned PHE to provide a best estimate of the health risks to people from ingesting contaminated objects via locally caught seafood and the uncertainties associated with these estimates.

This report describes the approach used in the assessment, the assessed health risks from consumption of seafood and a discussion of the sensitivity of these health risks to the assumptions made in the assessment. Health risks to commercial fishermen have also been assessed. The overall health risks to both seafood consumers and commercial fishermen are very low. The highest risks of radiation-induced fatal cancer (97.5th percentile of the distribution) are of the order of ten thousand times smaller than the level of risk that the Health and Safety Executive considers to be the upper limit for an acceptable level of risk. The main uncertainties associated with the estimation of the health risks have also been identified."

The overall risks are shown in Table 17, illustrating that risks to adults and children using the beach and consuming seafood are very low. In order to put these risks into context, a risk of between 1E-07 – 1E-08 per year is the annual risk of a fatal dog bite or insect sting (Brown & Etherington, 2011) and are therefore around 1000 times more likely than a radiation induced fatal cancer from exposure to radioactive particles in the environment.

Table 17: Risks of fatal cancer associated with encountering radioactive particles on the Cumbrian coast.

Find type	Beach user (risk yr^{-1})		Seafood consumer (risk yr^{-1})*	
	Adult	1 year old child	Adult	10 year old child
Alpha rich particle	2E-12	8E-12	6E-11	6E-12
Beta rich particle	9E-14$	3E-13$	5E-13	6E-14
Overall	2E-12	8E-12	6E-11	6E-12

*Based on probabilistic risk assessment (Oatway W and Brown J, 2015a)
$ Data are from Groundhog Evolution2 (Brown & Etherington, 2011) all other data are from Groundhog Synergy and Evolution2 ((Etherington, et al., 2012; Oatway & Brown, 2015b).

As new information becomes available regarding the continued monitoring of the Cumbrian beaches and from the further analysis of finds, PHE have been requested to update their recommendations, if supported by available evidence. A full review of the available data has been started in February 2017 and it is expected that an updated assessment of the health risk to the public from radioactive objects found on the beaches near the Sellafield site will be available during 2017/18.

8 Forward Programme

8.1 Proposed Beach Monitoring Programme for 2017

In a change to previous years, future beach monitoring programmes will align with the calendar year rather than the financial year. This change allows the beach monitoring programme to run alongside the wider environmental programme, making reporting and management of the programmes more efficient.

For 2017, a programme of 150 ha has been developed to meet the primary aim of providing reassurance that overall risks to beach users remain at or below those estimated in the PHE risk assessment. The programme follows the familiar template of recent years, with the 150 ha to be split into three programmes: a Sellafield programme (totalling 83 ha), a near-field programme (totalling 62 ha) and a far field programme (totalling 5 ha). The near-field programme will focus on the beaches at Seascale, Braystones and St. Bees, whereas the far-field programme will focus solely on the beach at Allonby.

Using one monitoring vehicle, such as the Metrac H5, the area that can be realistically achieved in a year is around 150 ha when taking into account the three periods of no monitoring (Easter, Summer and Christmas school holidays), the constraints of tides, restrictions of daylight hours and allowing time to conduct walked strandlines and occasional vehicle/equipment maintenance.

Sellafield Ltd believes the agreed monitoring programme is commensurate with the programme objectives and is capable of providing reassurance that risks remain very low. The programme fits with Public Health England's advice for; *"Continued regular monitoring of Sellafield beach and monitoring at one or two other beaches with high public occupancy, to provide continued reassurance that risks remain very low."* (Brown & Etherington, 2011; Etherington, et al., 2012).

The proposal was discussed and agreed at the February 2017 meeting of the Sellafield Particles Working Group. Any changes to the programme, which may stem from abnormal finds, difficulties in accessing the proposed beaches or other operational issues, will be made in full consultation with the EA.

The 2017 scheduled target areas for each beach are given in Table 18, with the full schedule displayed in Figure 23.

Note: To enable the transition between financial and calendar year programmes, Quarter 1 of the 2017 programme is carried over from Quarter 4 of the 2016/17 programme, and remains unchanged.

Table 18: Planned area coverage (ha) for each beach in 2017.

Programme	Beach	Sellafield	Near-Field	Far-Field	Total
Sellafield	Sellafield	83	-	-	83
Near-Field	Braystones	-	22	-	22
	St. Bees	-	20	-	20
	Seascale	-	20	-	20
Far-Field	Allonby	-	-	5	5
Total		83	62	5	150

	Week Starting	Beach Monitoring	Sellafield Programme: Area Targets (ha)	Near-Field Programme: Target Area (ha)	Far-Field Programme: Target Area (ha)
Q1 2017	02-Jan-17	St Bees (1)		4	
	09-Jan-17				
	16-Jan-17	Seascale (1) and Drigg Strandline Monitoring		4	
	23-Jan-17	Sellafield (1)	22		
	30-Jan-17				
	06-Feb-17				
	13-Feb-17				
	20-Feb-17				
	27-Feb-17	Braystones (1)		6	
	06-Mar-17				
	13-Mar-17	Walking Strandline Monitoring			
	20-Mar-17	St Bees (2)		4	
	27-Mar-17	Seascale (2)		4	
Q2 2017	03-Apr-17	Allonby (1)			5
	10-Apr-17	No Monitoring (Easter Holidays)			
	17-Apr-17				
	24-Apr-17	St Bees (3)		4	
	01-May-17	Seascale (3)		4	
	08-May-17	Sellafield (2)	28		
	15-May-17				
	22-May-17				
	29-May-17				
	05-Jun-17				
	12-Jun-17				
	19-Jun-17				
	26-Jun-17	Braystones (2)		8	
Q3 2017	03-Jul-17				
	10-Jul-17	St Bees (4)		4	
	17-Jul-17	Seascale (4)		4	
	24-Jul-17	No Monitoring (Summer Holidays)			
	31-Jul-17				
	07-Aug-17				
	14-Aug-17				
	21-Aug-17				
	28-Aug-17				
	04-Sep-17	St Bees (5)		4	
	11-Sep-17	Seascale (5)		4	
	18-Sep-17	Walking Strandline Monitoring			
	25-Sep-17	Sellafield (3)	33		
Q4 2017	02-Oct-17				
	09-Oct-17				
	16-Oct-17				
	23-Oct-17				
	30-Oct-17				
	06-Nov-17				
	13-Nov-17				
	20-Nov-17				
	27-Nov-17				
	04-Dec-17	Braystones (3)		8	
	11-Dec-17				
	18-Dec-17	Maintenance Week			
	25-Dec-17	No Monitoring (Christmas Holidays)			
		Cumulative Totals ==>	**83 ha**	**62 ha**	**5 ha**
		OVERALL TOTAL ==>	**150 ha**		

Figure 23: 2017 beach monitoring programme.

8.2 Investigation Programme for 2017/18

Two items of further research are proposed for 2017/18, these are an update of the Conceptual Site Model following the coastal geomorphology work performed last year and an update of PHE risk assessment by Brown & Etherington (2011). These are required as part of the BAT assessment for the programme (see Section 5) and to close out items in the forward strategy (see Section 8.4).

8.2.1 Update of the Conceptual Site Model of the Cumbrian Coast

Section 5.2.1 details the review of Coastal Geomorphology and Sediment Transport conducted in 2016/17. The output from this work now needs to be accommodated within the Conceptual Site Model (CSM) originally produced in 2014 (Rankine & Jackson, 2014).

8.2.2 Update of the PHE risk assessment (Brown & Etherington, 2011)

The risk assessment 'Health Risks from Radioactive Objects on Beaches in the Vicinity of the Sellafield Site' by Brown & Etherington (2011) was based on the available beach monitoring data of the time – between 2006 and 2009. Since then a wealth of beach monitoring information and analytical data have become available and considered (Etherington *et al*. (2012); Oatway & Brown (2015b); Golder (2016a; b; c; 2017a; b). To this end, PHE has been requested by the EA to review the health risks posed by radioactive objects in the environment around the Sellafield site. This risk assessment, to be completed during 2018, will include a review of many factors including habit data, activity distributions on objects, object populations, radiochemical content of objects and health risks posed by these objects.

8.3 Beach Find Analysis for 2017/18

8.3.1 Analysis for ^{137}Cs and ^{90}Sr Ratios of Beta rich Particle Finds

Particles with potentially high ^{90}Sr content will be analysed to address concerns expressed in the PHE risk assessment (Brown & Etherington, 2011). They recommended to the EA that beach particles with ^{137}Cs activity greater than 1E+05 Bq should be characterised in terms of size and chemical composition, and their ^{90}Sr content should be measured. The skin dose from such finds should be calculated or measured to assess if dose rates in excess of 300 mGy h^{-1} are possible.

A contract has been placed with Golder Associates (UK) Ltd for this work between 2016 and 2018 under the project "ESR 199".

Of the 374 Beta-rich particles recovered to data, only one had a ^{137}Cs activity greater than 1E+05 Bq and this has been analysed. The ^{137}Cs activities of the remaining beach particles are 6.0E+04 Bq per find or lower.

8.4 Particles Programme Forward Strategy

A forward strategy for the particles programme has been developed in consultation with the Sellafield Particles working group (comprising of NDA, PHE, EA and FSA) and COMARE Contaminants working group. Details of developing the strategy and the prioritisation of tasks have been given previously in Sellafield Ltd (2016). Twelve tasks were identified and ranked as being high or medium priority and their latest status are shown in Table 19. It should be noted that the list in Table 19 has been optimised so some of the listed tasks meet several of the requirements detailed in the workplan.

Table 19: Tasks that were assessed as medium and high priority.

Tasks	Status
Synergy 2 trials and investigation into improved detection techniques (*e.g.* plastic phosphor scintillation detectors).	Completed (see 2015/16 Report).
PHE to conduct a reappraisal of the Risk Assessment following the Synergy 2 trials (to be completed before 2018).	Ongoing (see Section 8.2.2).
Evaluate the detection efficiency of Synergy 2 for buried particles.	Completed (see 2015/16 Report).
Design of beach monitoring programme to focus on high find rate beaches.	Ongoing (see Section 8.1).
Analysis of beach monitoring repeat areas to understand repopulation rates.	Ongoing (see Sections 4.3.1 and 8.1).
Conduct a geomorphology review to include existing knowledge of bulk sediment movement on the West Cumbrian coast and include analysis of beach height data from ongoing beach monitoring programme.	Completed (Section 5.2.1).
Ongoing pro-active response to storm events.	Ongoing (see Section 4.3).
Sellafield Ltd to review photographic data including the use of drones.	Completed (Section 5.2.2).
PHE to review the effective doses associated with the 2014 Seascale ^{90}Sr rich particle (S1164/SEA) and are to provide a letter response.	Completed.
PHE conducting dose rate measurement work to advise on best techniques.	Ongoing (see Section 4.6.5).
Sellafield Ltd to develop staged proposals on optimising the sentinel monitoring programme.	Ongoing in consultation with stakeholders (see Section 6.3.)
Characterisation of finds from site (*e.g.* drainage finds containing [Hg]). Gully pot samples sent as part of characterisation. The RSR permit compliance requires Sellafield Ltd to use BAT to avoid release in future and therefore there is an ongoing routine action on Plant to demonstrate compliance.	Moved to routine programme.

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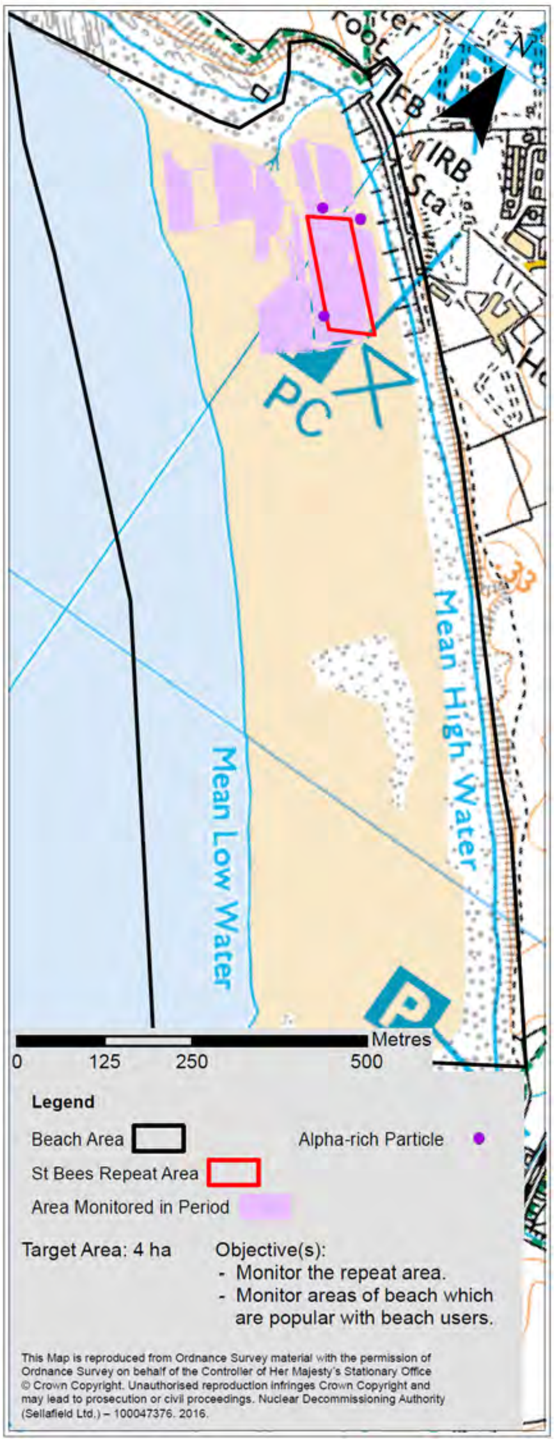
Appendix 1: Beach Monitoring and Find Maps

St Bees (1) Area
Monitoring completed between
11th and 14th April 2016



Seascale (1) Area
Monitoring completed between
18th and 21st April 2016

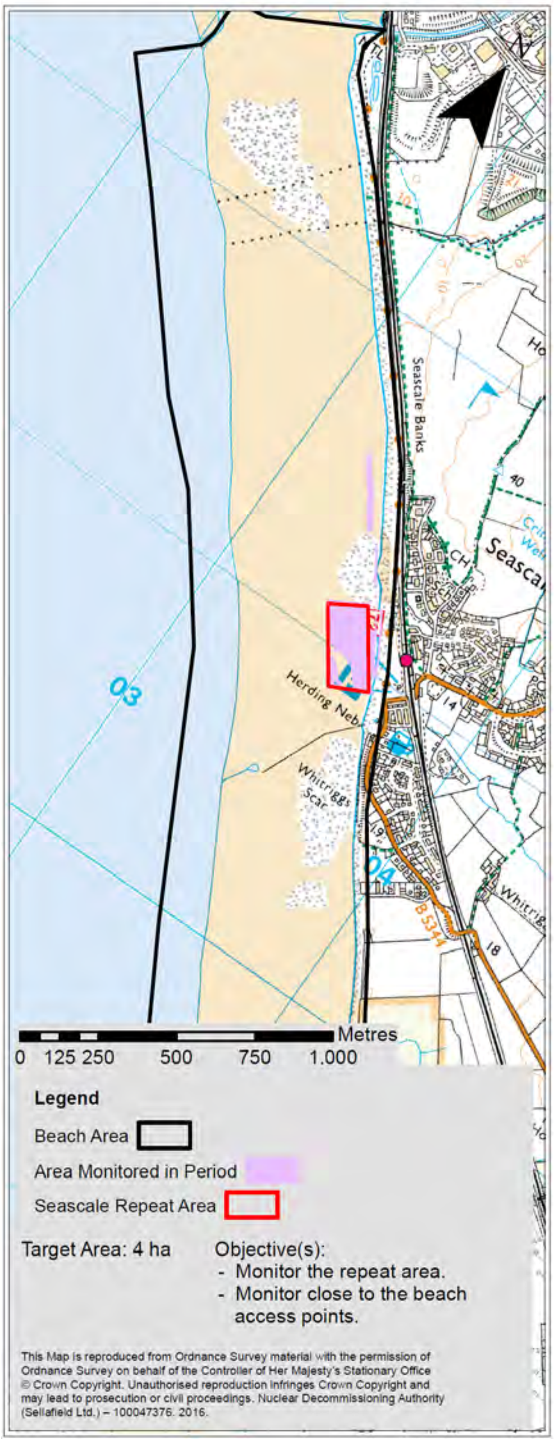
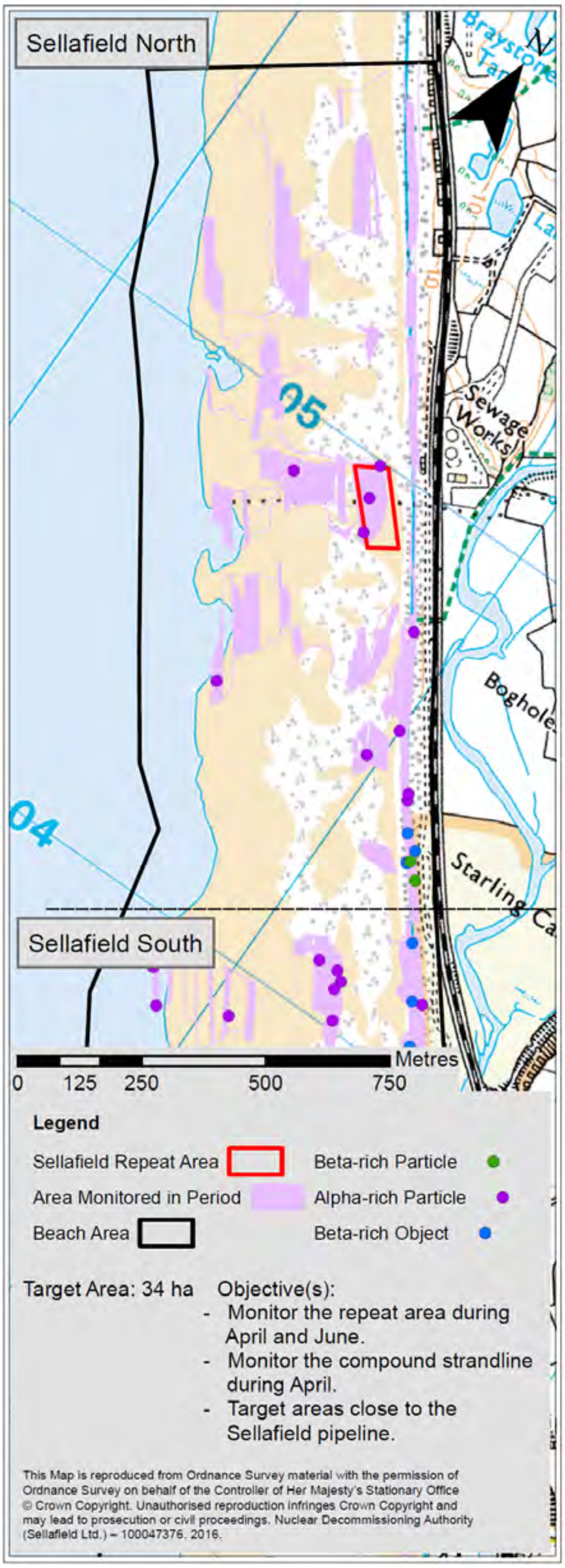


Figure A1.1 St. Bees and Seascale beach visits in April 2016.

Sellafield (1) Area - Monitoring completed between 25th April and 24th June 2016



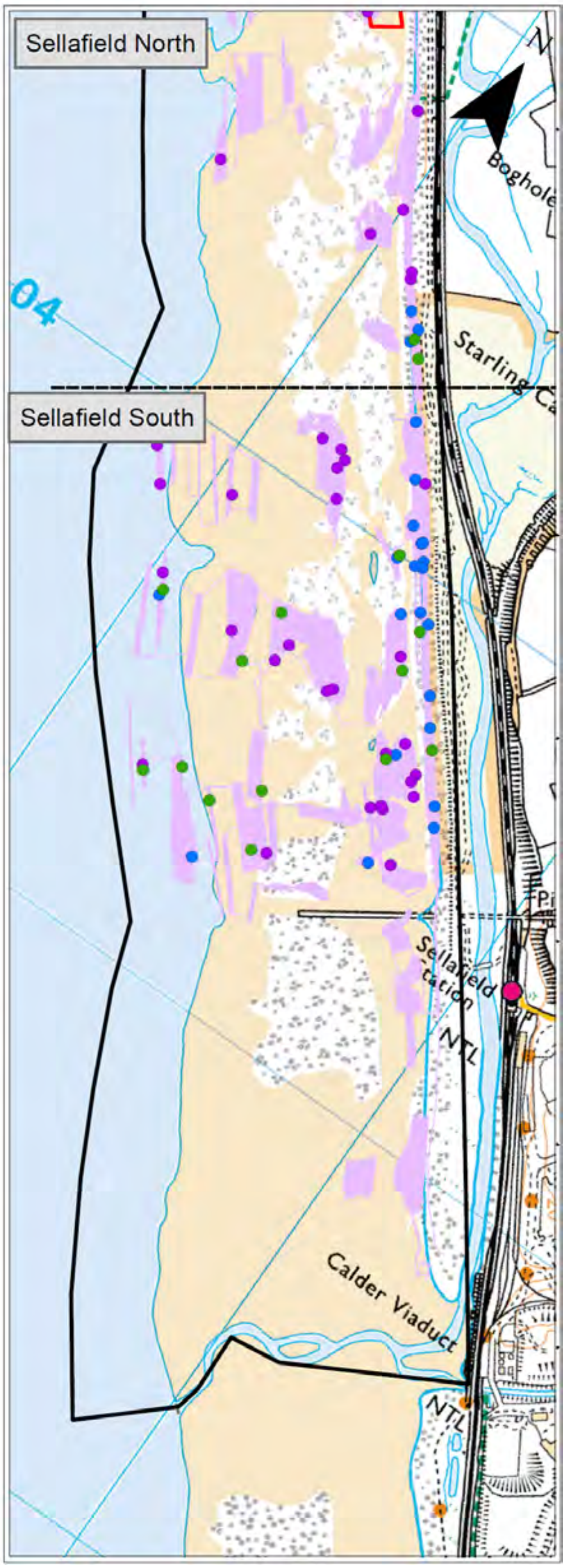
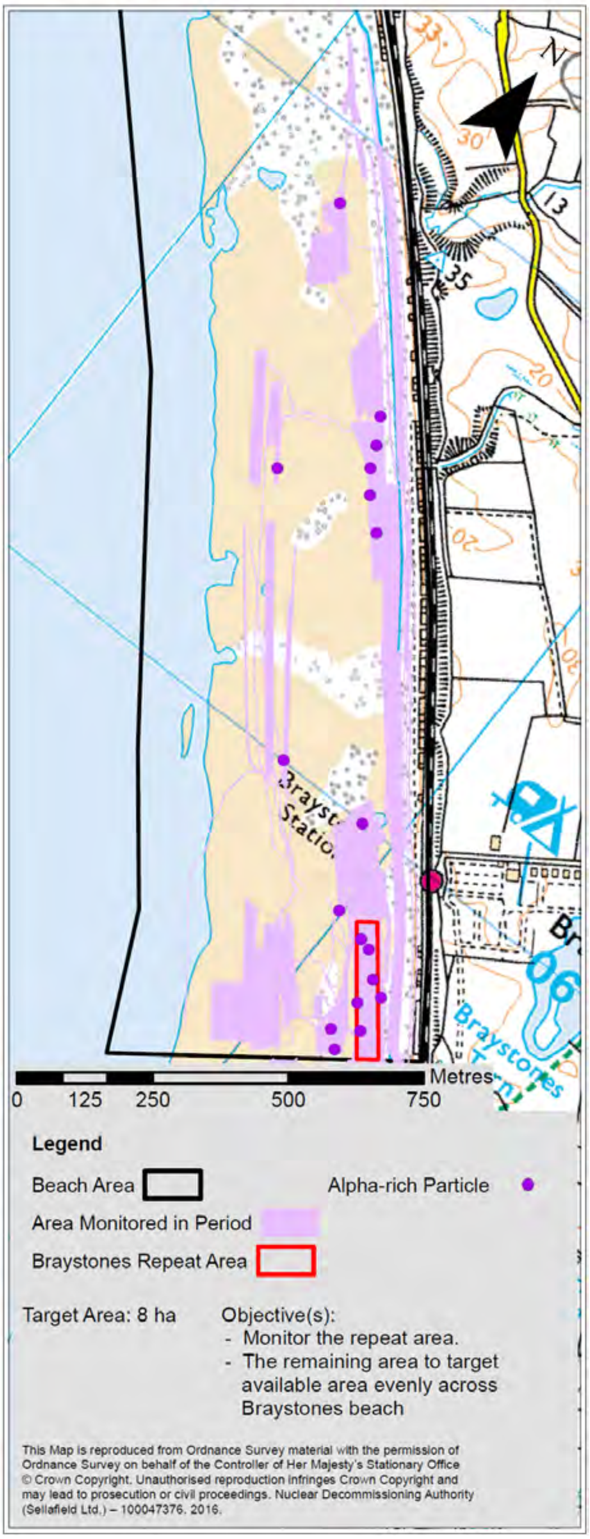


Figure A1.2 Sellafield beach visits in April, May and June 2016.

Braystones (1) Area
Monitoring completed between 27th June and 7th July 2016



St Bees (2) Area
Monitoring completed between 11th and 14th July 2016

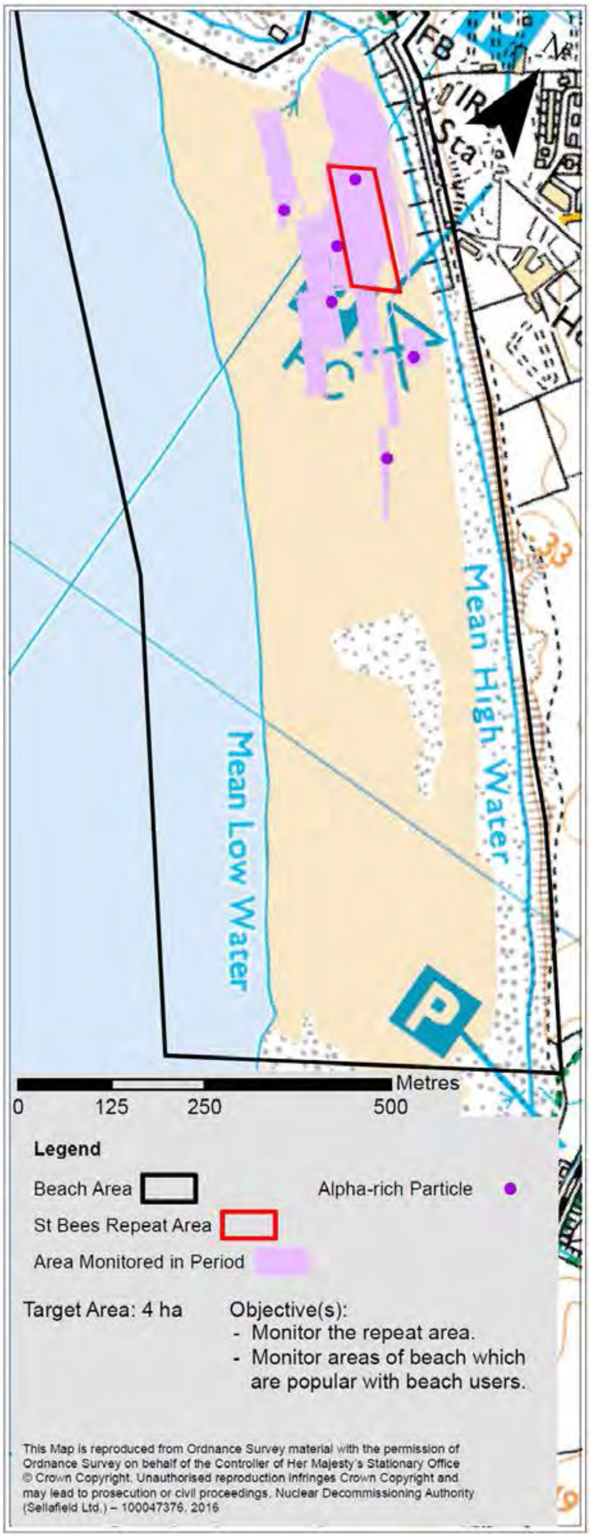


Figure A1.3 Braystones and St. Bees beach visits in June and July 2016.

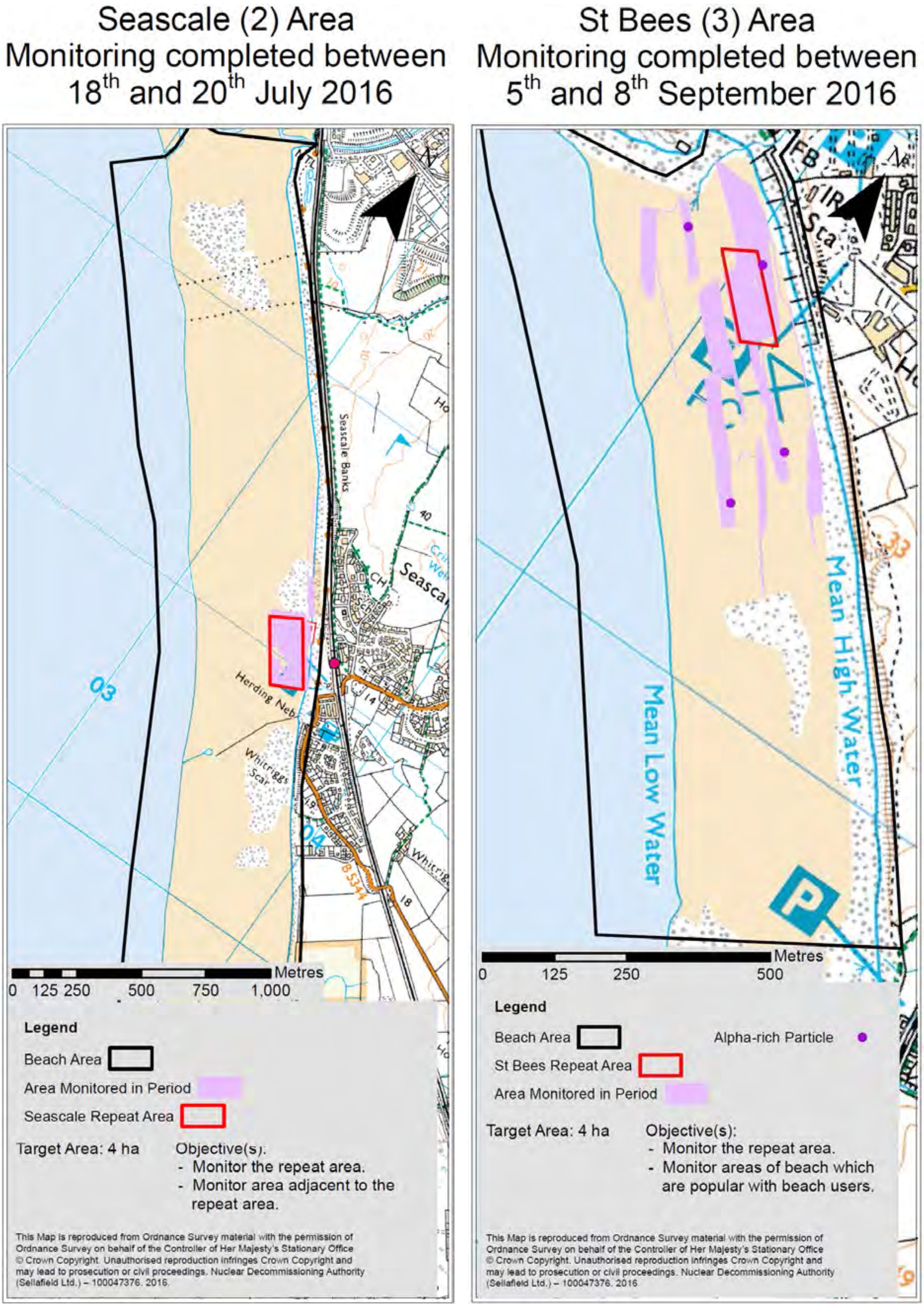


Figure A1.4 Seascale and St. Bees beach visits in July and September 2016.

Seascale (3) Area
Monitoring completed between
12th and 15th September 2016

Allonby (1) Area
Monitoring completed between
26th September and 7th October 2016

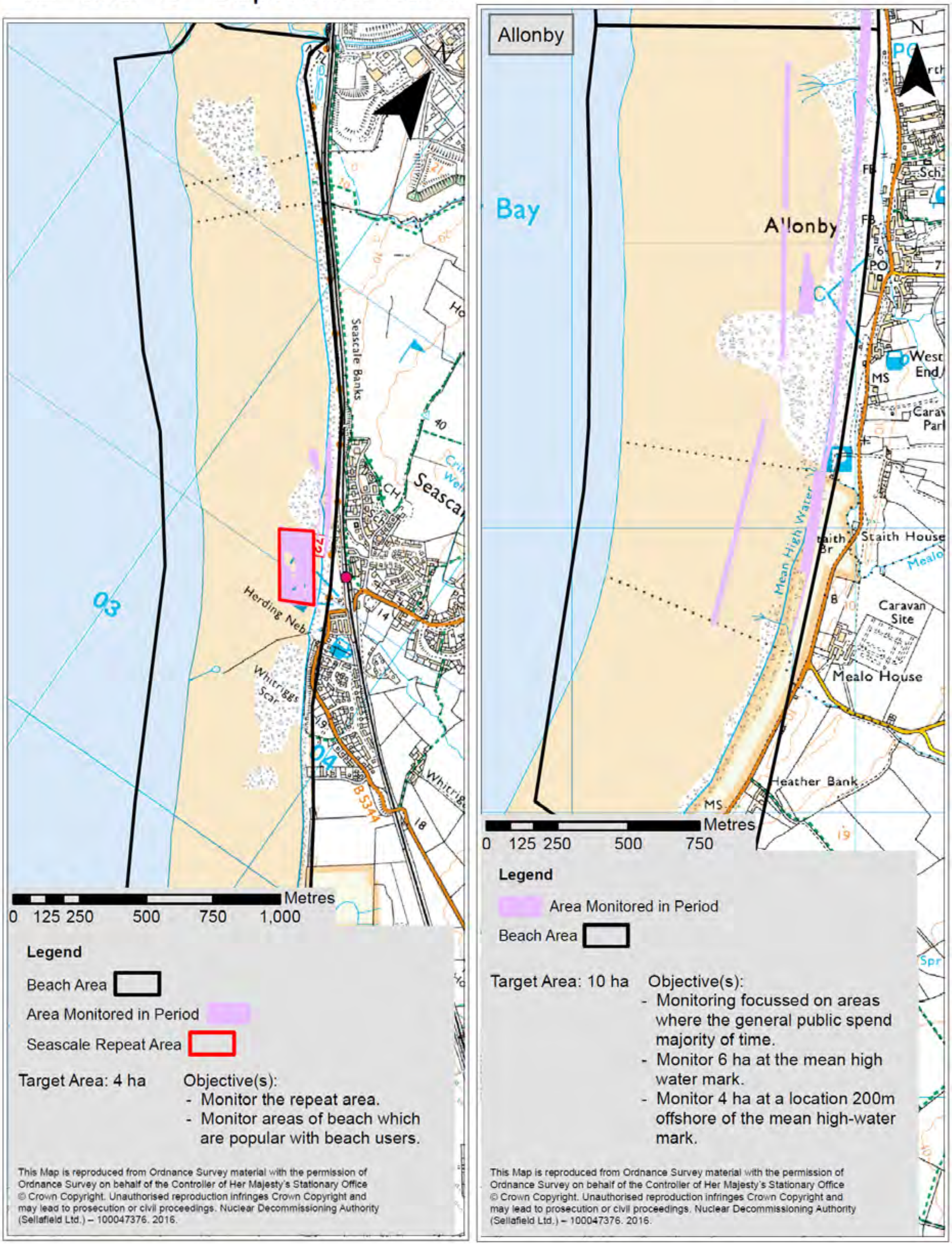


Figure A1.5 Seascale and Allonby beach visits in September and October 2016.

Sellafield (2) Area - Monitoring completed between 10th October and 1st December 2016

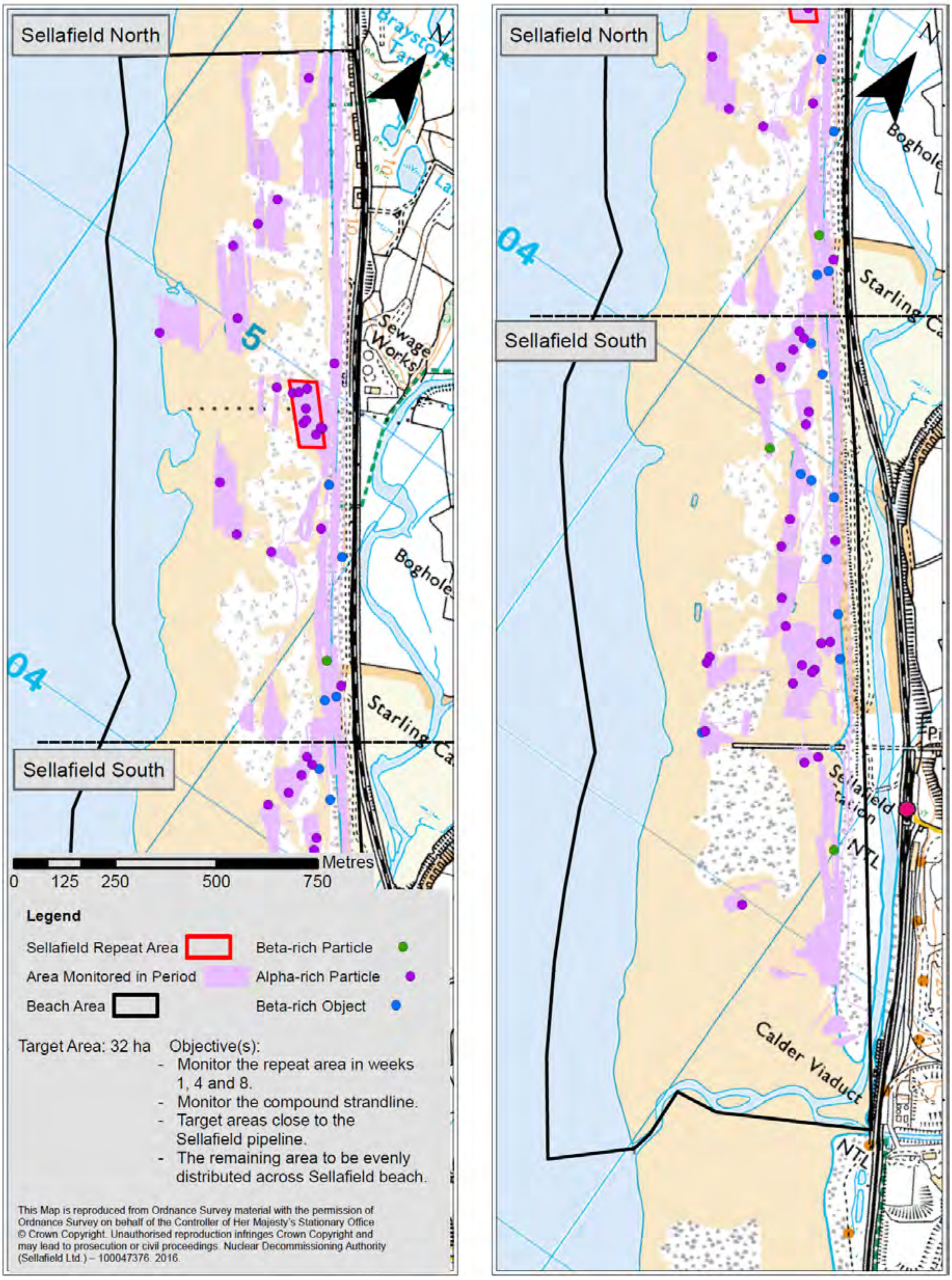


Figure A1.6 Sellafield beach visits in October, November and December 2016.

Braystones (2) Area
Monitoring completed between
5th and 16th December 2016

St Bees (4) Area
Monitoring completed between
4th and 10th January 2017

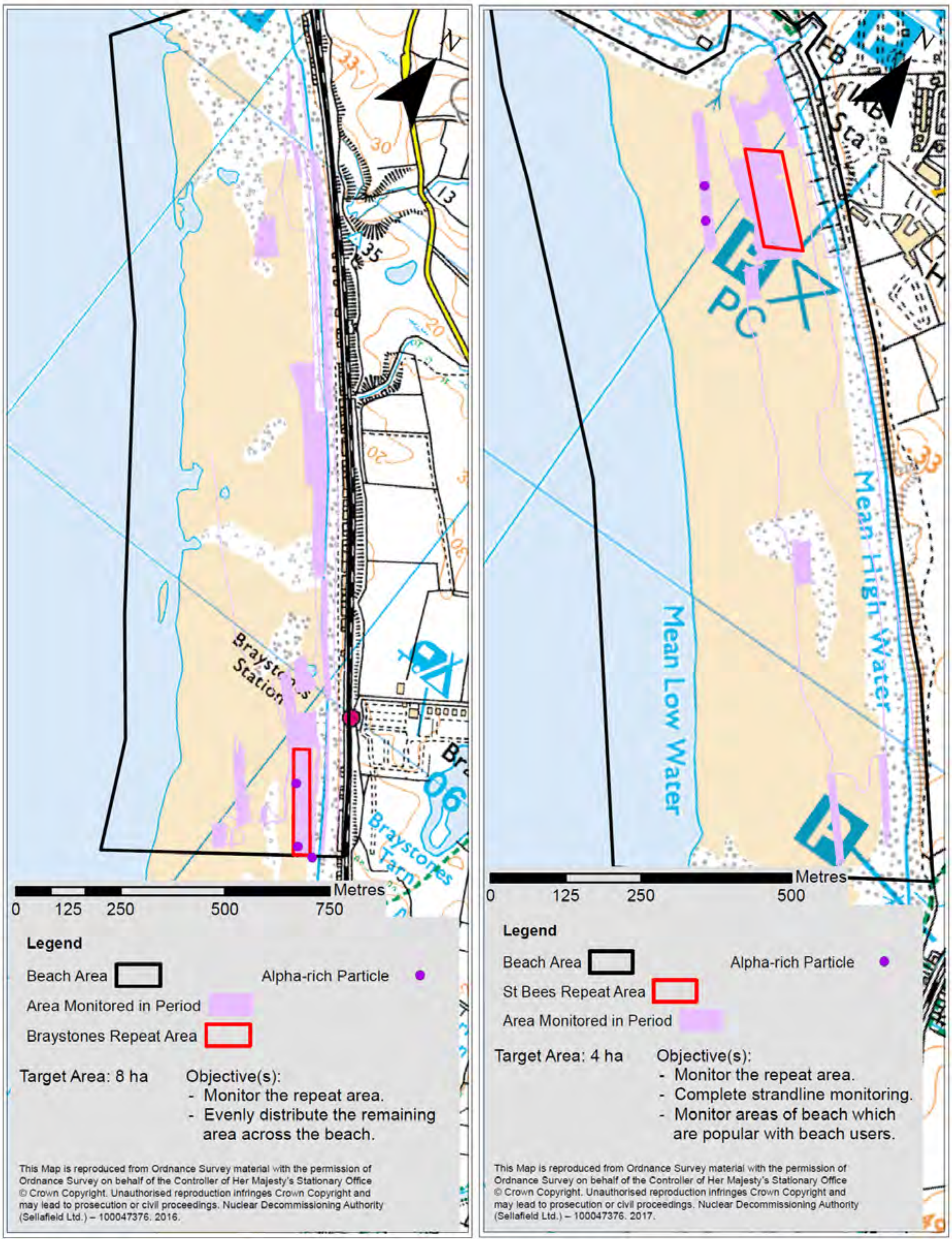


Figure A1.7 Braystones and St. Bees beach visits in December 2016 and January 2017.

Drigg Strandline
Monitoring completed on
16th January 2017

Seascale (4) Area
Monitoring completed between
17th and 19th January 2017

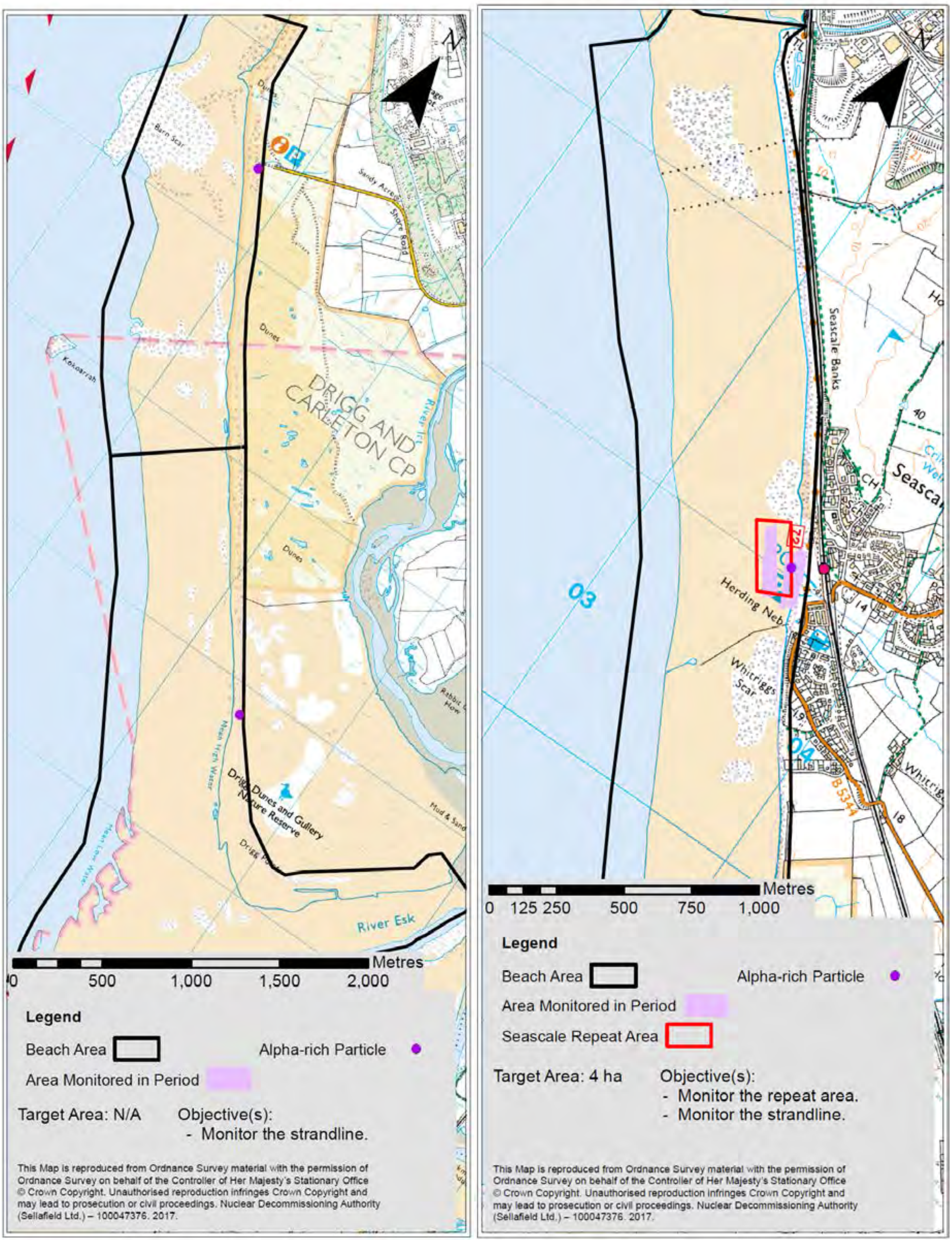


Figure A1.8 Drigg and Seascale beach visits in January 2017.

Sellafield (3) Area - Monitoring completed between 23rd January and 22nd February 2017

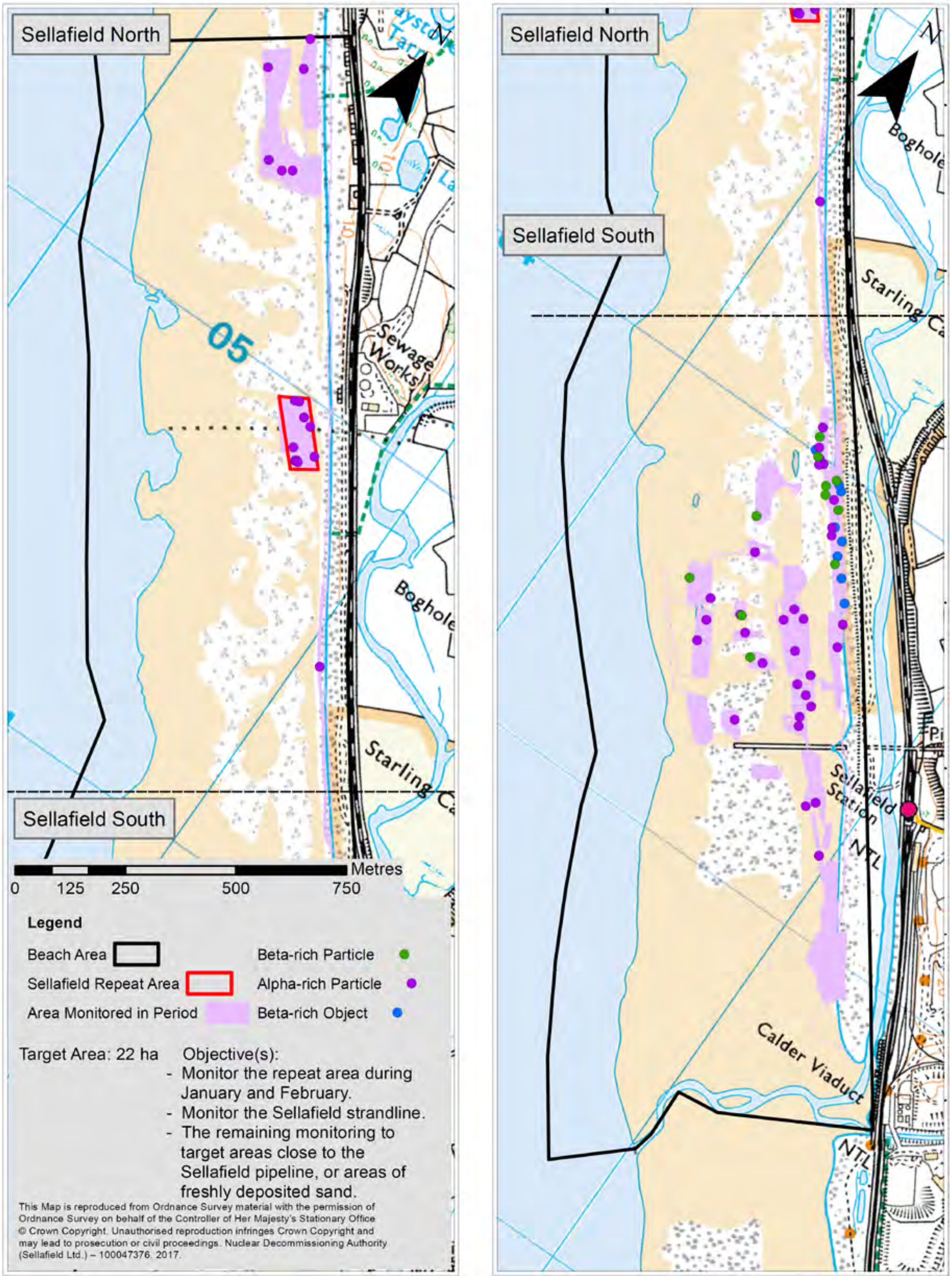
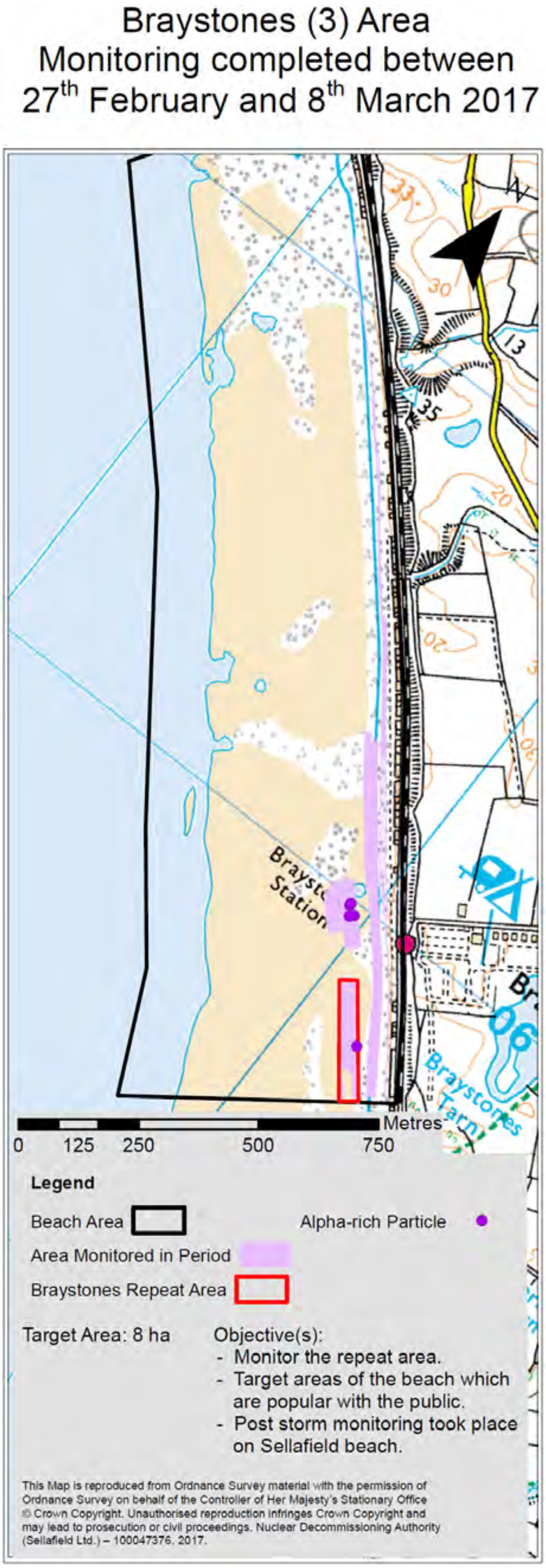


Figure A1.9 Sellafield beach visit in January and February 2017.



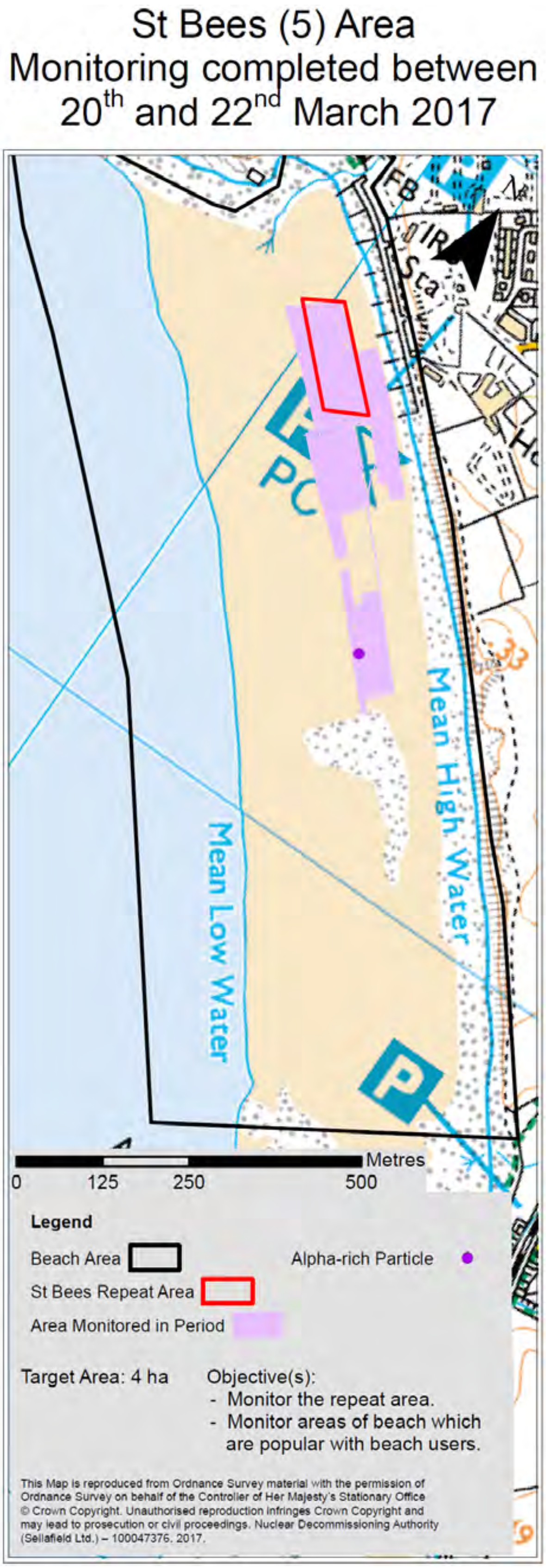


Figure A1.10 Braystones and St. Bees beach visits in February and March 2017.

Seascale (5) Area
Monitoring completed between
27th and 29th March 2017

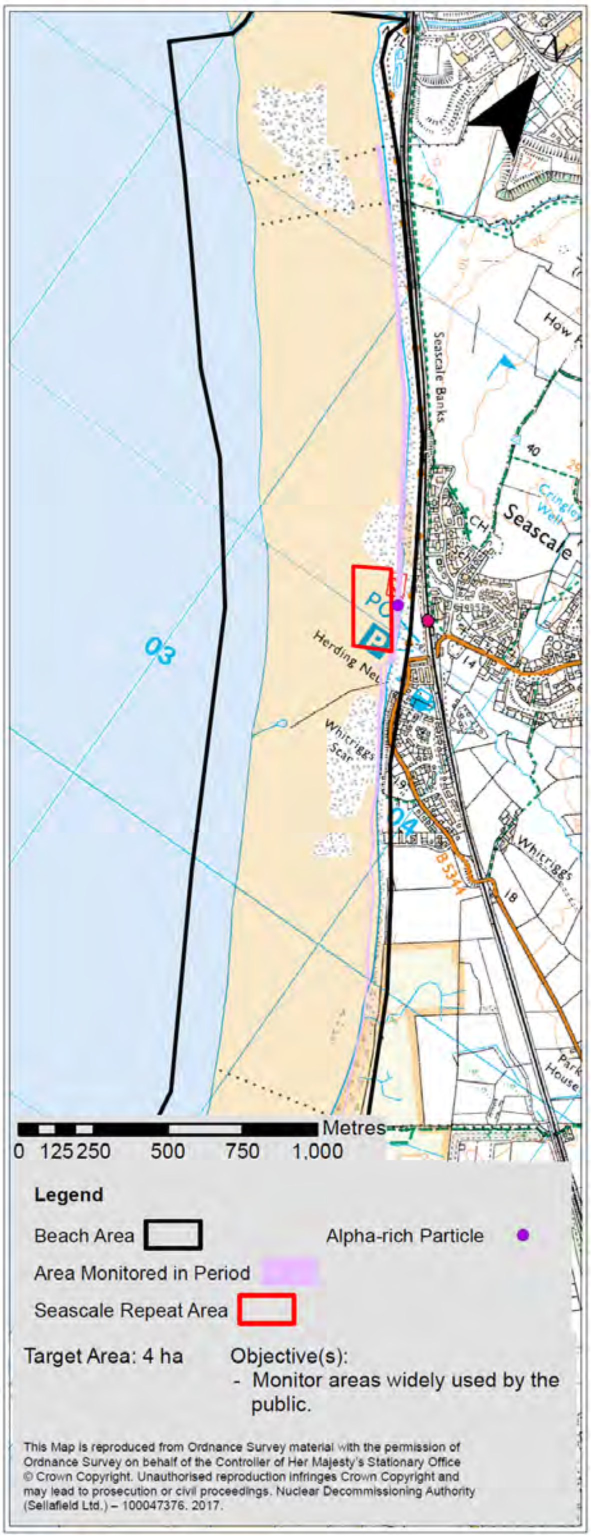


Figure A1.11 Seascale beach visits in March 2017.

Appendix 2: Summary Monitoring Data to the end of March 2017

Table A2.1 Total area monitored and finds by category and beach to the end of March 2017.

Beach location	Area covered ha	Alpha rich particle	Alpha rich object	Beta rich particle	Beta rich object	^{60}Co rich particle	^{60}Co rich object	Total particles found	Total objects found
Allonby	82.9	13	0	2	0	0	0	15	0
Workington	24.0	5	0	1	1	0	0	6	1
Harrington	8.6	4	0	0	0	0	0	4	0
Whitehaven	8.8	8	0	1	0	0	0	9	0
St. Bees	346.3	233	0	15	0	2	0	250	0
Braystones	340.2	402	0	35	0	4	0	441	0
Sellafield [1]	606.5	1034	6	299	657	8	2	1341	665
Seascale	333.7	63	0	23	3	0	1	86	4
Drigg	142.6	25	0	2	1	0	1	27	2
TOTAL [1]	1893.5	1787	6	378	662	14	4	2179	672

Note 1: The total area excludes monitoring from other beach areas (Southerness 14.3 ha, Goatwell Bay 5.8 ha, Parton 1.9 ha, Nethertown 2.5 ha and Silecroft 12.1 ha). Including this additional area gives an overall total of 1930.0 ha. No finds were made during these additional surveys.

Table A2.2 Particle and object activity summary by category and monitoring system to the end of March 2017.

Activities in Bq	Classification								
	Alpha rich			Beta rich			Co60 rich		
	Pre-Synergy	Synergy	Synergy 2	Pre-Synergy	Synergy	Synergy 2	Pre-Synergy	Synergy	Synergy 2
Total number	62	983	749	599	206	235	11	6	1
No. of particles	59	980	749	190	103	85	7	6	1
No. of objects	3	3	0	409	103	150	4	0	0
Particle Mean Am-241	7.82E+04	3.00E+04	2.59E+04	3.72E+02	5.45E+02	2.22E+02	-	-	-
Particle Max. Am-241	6.34E+05	2.52E+05	1.46E+05	1.15E+03	1.63E+03	7.17E+02	-	-	-
Number of Particles Containing Am-241	59	980	749	17	11	15	0	0	0
Object Mean Am-241	1.74E+04	2.40E+05	0.00E+00	7.62E+02	4.15E+02	6.51E+02	4.48E+03	-	-
Object Max. Am-241	3.54E+04	6.18E+05	0.00E+00	4.99E+03	1.17E+03	5.27E+03	4.48E+03	-	-
Number of Objects Containing Am-241	3	3	0	59	14	36	1	0	0
Particle Mean Cs-137	4.09E+01	1.99E+01	3.02E+02	1.51E+04	1.81E+04	2.10E+04	-	8.41E+01	-
Particle Max. Cs-137	6.09E+01	3.36E+01	7.38E+03	6.52E+04	2.92E+05	5.91E+04	-	8.41E+01	-
Number of Particles Containing Cs-137	2	7	25	190	103	85	0	1	0
Object Mean Cs-137	7.04E+03	5.46E+01	-	3.94E+04	5.94E+04	9.22E+04	8.17E+01	-	-
Object Max. Cs-137	7.20E+03	5.46E+01	-	8.75E+05	1.04E+06	3.73E+06	8.17E+01	-	-
Number of Objects Containing Cs-137	2	1	0	409	103	150	1	0	0
Particle Mean Co-60	8.85E+00	1.03E+01	-	7.91E+01	-	-	1.37E+04	7.35E+03	1.09E+04
Particle Max. Co-60	8.85E+00	1.65E+01	-	2.42E+02	-	-	1.97E+04	2.38E+04	1.09E+04
Number of Particles Containing Co-60	1	7	0	4	0	0	7	6	1
Object Mean Co-60	- [1]	-	-	1.06E+02	-	-	1.37E+04	-	-
Object Max. Co-60	-	-	-	5.33E+02	-	-	2.35E+04	-	-
Number of Objects Containing Co-60	0	0	0	7	0	0	4	0	0

Note 1: Where no analysis results above the detection limit have been reported or no finds have been recovered, the activity is indicated by "–"
Note 2: The total number of Alpha-rich Synergy particles differs from the total derived from Table A2.1 due to the inclusion of the Alpha-rich seabed find
Note 3: the Table excludes to two stones containing ^{226}Ra

Table A2.3 Total area monitored and finds by category, beach and financial year (years reported only when monitoring has been performed).

Beach Location	**Financial Year**	**Area Monitored in Hectares**	**Find category & Type**					
			Alpha rich particle	**Alpha rich object**	**Beta rich particle**	**Beta rich object**	**^{60}Co rich particle**	**^{60}Co rich object**
Allonby	2008/2009	10.9	0	0	1	0	0	0
	2010/2011	7.5	0	0	0	0	0	0
	2011/2012	12.4	1	0	0	0	0	0
	2012/2013	10.0	3	0	0	0	0	0
	2013/2014	8.0	2	0	0	0	0	0
	2014/2015 Synergy 2	13.1	7	0	1	0	0	0
	2015/2016	10.4	0	0	0	0	0	0
	2016/2017	10.7	0	0	0	0	0	0
Workington	2008/2009	10.5	0	0	1	0	0	0
	2012/2013	3.2	1	0	0	0	0	0
	2013/2014	5.8	1	0	0	0	0	0
	2014/2015 Synergy 2	4.5	3	0	0	1	0	0
Harrington	2010/2011	2.5	2	0	0	0	0	0
	2011/2012	2.6	1	0	0	0	0	0
	2012/2013	1.0	1	0	0	0	0	0
	2013/2014	0.9	0	0	0	0	0	0
	2014/2015 Synergy 2	1.7	0	0	0	0	0	0
Whitehaven	2007/2008	1.5	0	0	0	0	0	0
	2010/2011	4.3	8	0	1	0	0	0
	2011/2012	2.0	0	0	0	0	0	0

Beach Location	Financial Year	Area Monitored in Hectares	Find category & Type					
			Alpha rich particle	Alpha rich object	Beta rich particle	Beta rich object	^{60}Co rich particle	^{60}Co rich object
St. Bees	2007/2008	26.0	2	0	4	0	0	0
	2008/2009	43.1	1	0	2	0	0	0
	2009/2010 Pre-Synergy	38.6	1	0	2	0	1	0
	2009/2010 Post-synergy	21.9	0	0	0	0	0	0
	2010/2011	43.9	57	0	3	0	0	0
	2011/2012	25.2	39	0	2	0	0	0
	2012/2013	26.4	8	0	0	0	0	0
	2013/2014	39.3	32	0	0	0	0	0
	2014/2015 Synergy	4.9	2	0	0	0	0	0
	2014/2015 Synergy 2	33.8	42	0	2	0	0	0
	2015/2016	21.3	33	0	0	0	1	0
	2016/2017	21.9	16	0	0	0	0	0
Braystones	2006/2007	7.0	1	0	2	0	0	0
	2007/2008	11.8	0	0	2	0	0	0
	2008/2009	19.1	0	0	3	0	0	0
	2009/2010 Pre-Synergy	21.4	2	0	2	0	0	0
	2009/2010 Post-synergy	30.8	57	0	6	0	1	0
	2010/2011	62.4	107	0	7	0	1	0
	2011/2012	46.4	55	0	4	0	1	0
	2012/2013	39.5	55	0	5	0	1	0
	2013/2014	34.9	25	0	3	0	0	0
	2014/2015 Synergy 2	19.0	57	0	0	0	0	0
	2015/2016	24.3	18	0	1	0	0	0
	2016/2017	23.6	25	0	0	0	0	0

Beach Location	Financial Year	Area Monitored in Hectares	Find category & Type					
			Alpha rich particle	Alpha rich object	Beta rich particle	Beta rich object	^{60}Co rich particle	^{60}Co rich object
Sellafield	2006/2007	5.5	0	0	2	7	0	0
	2007/2008	65.7	24	2	77	226	2	1
	2008/2009	97.0	19	0	53	147	2	0
	2009/2010 Pre-Synergy	26.8	2	1	20	25	2	1
	2009/2010 Post-synergy	23.8	68	1	9	23	0	0
	2010/2011	49.7	126	2	12	37	0	0
	2011/2012	43.3	124	0	21	13	1	0
	2012/2013	44.6	122	0	21	22	1	0
	2013/2014	40.9	34	0	5	8	0	0
	2014/2015 Synergy 2	38.2	174	0	30	40	0	0
	2015/2016	83.1	206	0	23	61	0	0
	2016/2017	87.9	135	0	26	48	0	0
Seascale	2007/2008	27.7	0	0	6	0	0	1
	2008/2009	61.3	3	0	7	3	0	0
	2009/2010 Pre-Synergy	37.6	1	0	4	0	0	0
	2009/2010 Post-synergy	39.1	9	0	3	0	0	0
	2010/2011	38.5	10	0	0	0	0	0
	2011/2012	15.1	2	0	0	0	0	0
	2012/2013	15.9	7	0	1	0	0	0
	2013/2014	13.0	7	0	0	0	0	0
	2014/2015 Synergy	3.2	0	0	0	0	0	0
	2014/2015 Synergy 2	33.7	17	0	2	0	0	0
	2015/2016	27.1	5	0	0	0	0	0
	2016/2017	21.5	2	0	0	0	0	0

Beach Location	**Financial Year**	**Area Monitored in Hectares**	**Find category & Type**					
			Alpha rich particle	**Alpha rich object**	**Beta rich particle**	**Beta rich object**	**^{60}Co rich particle**	**^{60}Co rich object**
Drigg	2007/2008	19.8	2	0	1	1	0	1
	2008/2009	33.7	1	0	1	0	0	0
	2009/2010 Pre-Synergy	0.01	0	0	0	0	0	0
	2009/2010 Post-synergy	19.5	0	0	0	0	0	0
	2010/2011	30.4	10	0	0	0	0	0
	2011/2012	8.8	3	0	0	0	0	0
	2012/2013	10.8	0	0	0	0	0	0
	2013/2014	9.2	0	0	0	0	0	0
	2014/2015 Synergy 2	8.3	5	0	0	0	0	0
	2015/2016	1.1	2	0	0	0	0	0
	2016/2017	1.1	2	0	0	0	0	0
Total	2007/08 – 2016/17	1893.5	1787	6	378	662	14	4

Table A2.4 Find rates by category, beach and financial year (years reported only when monitoring has been performed)

Beach Location	Financial Year	Find rate by Find category & Type (per ha)						
		Area Monitored in Hectares	Alpha rich particle	Alpha rich object	Beta rich particle	Beta rich object	^{60}Co rich particle	^{60}Co rich object
Allonby	2008/2009	10.9	No Finds	No Finds	<0.1	No Finds	No Finds	No Finds
	2010/2011	7.5	IA	IA	IA	IA	IA	IA
	2011/2012	12.4	<0.1	No Finds	No Finds	No Finds	No Finds	No Finds
	2012/2013	10.0	<1	No Finds	No Finds	No Finds	No Finds	No Finds
	2013/2014	8.0	IA	IA	IA	IA	IA	IA
	2014/2015 Synergy 2	13.1	<1	No Finds	<0.1	No Finds	No Finds	No Finds
	2015/2016	10.4	No Finds	No Finds	No Finds	No Finds	No Finds	No Finds
	2016/2017	10.7	No Finds	No Finds	No Finds	No Finds	No Finds	No Finds
Workington	2008/2009	10.5	No Finds	No Finds	<0.1	No Finds	No Finds	No Finds
	2012/2013	3.2	IA	IA	IA	IA	IA	IA
	2013/2014	5.8	IA	IA	IA	IA	IA	IA
	2014/2015 Synergy 2	4.5	IA	IA	IA	IA	IA	IA
Harrington	2010/2011	2.5	IA	IA	IA	IA	IA	IA
	2011/2012	2.6	IA	IA	IA	IA	IA	IA
	2012/2013	1.0	IA	IA	IA	IA	IA	IA
	2013/2014	0.9	IA	IA	IA	IA	IA	IA
	2014/2015 Synergy 2	1.7	IA	IA	IA	IA	IA	IA
Whitehaven	2007/2008	1.5	IA	IA	IA	IA	IA	IA
	2010/2011	4.3	IA	IA	IA	IA	IA	IA
	2011/2012	2.0	IA	IA	IA	IA	IA	IA

Beach Location	Financial Year	Find rate by Find category & Type (per ha)						
		Area Monitored in Hectares	Alpha rich particle	Alpha rich object	Beta rich particle	Beta rich object	^{60}Co rich particle	^{60}Co rich object
St. Bees	2007/2008	26.0	<0.1	No Finds	<1	No Finds	No Finds	No Finds
	2008/2009	43.1	<0.1	No Finds	<0.1	No Finds	No Finds	No Finds
	2009/2010 Pre-Synergy	38.6	<0.1	No Finds	<0.1	No Finds	<0.1	No Finds
	2009/2010 Post-synergy	21.9	No Finds	No Finds	No Finds	No Finds	No Finds	No Finds
	2010/2011	43.9	1	No Finds	<0.1	No Finds	No Finds	No Finds
	2011/2012	25.2	2	No Finds	<0.1	No Finds	No Finds	No Finds
	2012/2013	26.4	<1	No Finds	No Finds	No Finds	No Finds	No Finds
	2013/2014	39.3	<1	No Finds	No Finds	No Finds	No Finds	No Finds
	2014/15 Synergy	4.9	IA	IA	IA	IA	IA	IA
	2014/2015 Synergy 2	33.8	1	No Finds	<0.1	No Finds	No Finds	No Finds
	2015/2016	21.3	2	No Finds	No Finds	No Finds	<0.1	No Finds
	2016/2017	21.9	1	No Finds	No Finds	No Finds	No Finds	No Finds

Beach Location	Financial Year	Find rate by Find category & Type (per ha)						
		Area Monitored in Hectares	Alpha rich particle	Alpha rich object	Beta rich particle	Beta rich object	^{60}Co rich particle	^{60}Co rich object
Braystones	2006/2007	7.0	IA	IA	IA	IA	IA	IA
	2007/2008	11.8	No Finds	No Finds	<1	No Finds	No Finds	No Finds
	2008/2009	19.1	No Finds	No Finds	<1	No Finds	No Finds	No Finds
	2009/2010 Pre-Synergy	21.4	<0.1	No Finds	<0.1	No Finds	No Finds	No Finds
	2009/2010 Post-synergy	30.8	2	No Finds	<1	No Finds	<0.1	No Finds
	2010/2011	62.4	2	No Finds	<1	No Finds	<0.1	No Finds
	2011/2012	46.4	1	No Finds	<0.1	No Finds	<0.1	No Finds
	2012/2013	39.5	1	No Finds	<1	No Finds	<0.1	No Finds
	2013/2014	34.9	<1	No Finds	<0.1	No Finds	No Finds	No Finds
	2014/2015 Synergy 2	19.0	3	No Finds	No Finds	No Finds	No Finds	No Finds
	2015/2016	24.3	<1	No Finds	<0.1	No Finds	No Finds	No Finds
	2016/2017	23.6	1	No Finds	No Finds	No Finds	No Finds	No Finds
Sellafield	2006/2007	5.5	IA	IA	IA	IA	IA	IA
	2007/2008	65.7	<1	<0.1	1	3	<0.1	<0.1
	2008/2009	97.0	<1	No Finds	<1	2	<0.1	No Finds
	2009/2010 Pre-Synergy	26.8	<0.1	<0.1	<1	<1	<0.1	<0.1
	2009/2010 Post-synergy	23.8	3	<0.1	<1	<1	No Finds	No Finds
	2010/2011	49.7	3	<0.1	<1	<1	No Finds	No Finds
	2011/2012	43.3	3	No Finds	<1	<1	<0.1	No Finds
	2012/2013	44.6	3	No Finds	<1	<1	<0.1	No Finds
	2013/2014	40.9	<1	No Finds	<1	<1	No Finds	No Finds
	2014/2015 Synergy 2	38.2	5	No Finds	<1	1	No Finds	No Finds
	2015/2016	83.1	2	No Finds	<1	<1	No Finds	No Finds
	2016/2017	87.9	2	No Finds	<1	<1	No Finds	No Finds

Beach Location	Financial Year	Find rate by Find category & Type (per ha)						
		Area Monitored in Hectares	Alpha rich particle	Alpha rich object	Beta rich particle	Beta rich object	^{60}Co rich particle	^{60}Co rich object
Seascale	2007/2008	27.7	No Finds	No Finds	<1	No Finds	No Finds	<0.1
Seascale	2008/2009	61.3	<0.1	No Finds	<1	<0.1	No Finds	No Finds
Seascale	2009/2010 Pre-Synergy	37.6	<0.1	No Finds	<1	No Finds	No Finds	No Finds
Seascale	2009/2010 Post-synergy	39.1	<1	No Finds	<0.1	No Finds	No Finds	No Finds
Seascale	2010/2011	38.5	<1	No Finds	No Finds	No Finds	No Finds	No Finds
Seascale	2011/2012	15.1	<1	No Finds	No Finds	No Finds	No Finds	No Finds
Seascale	2012/2013	15.9	<1	No Finds	<0.1	No Finds	No Finds	No Finds
Seascale	2013/2014	13.0	<1	No Finds	No Finds	No Finds	No Finds	No Finds
Seascale	2014/15 Synergy	3.2	IA	IA	IA	IA	IA	IA
Seascale	2014/2015 Synergy 2	33.7	<1	No Finds	<0.1	No Finds	No Finds	No Finds
Seascale	2015/2016	27.1	<1	No Finds	No Finds	No Finds	No Finds	No Finds
Seascale	2016/2017	21.5	<0.1	No Finds	No Finds	No Finds	No Finds	No Finds
Drigg	2007/2008	19.8	<1	No Finds	<1	No Finds	<0.1	No Finds
Drigg	2008/2009	33.7	<0.1	No Finds	<0.1	No Finds	No Finds	No Finds
Drigg	2009/2010 Pre-Synergy	0.01	IA	IA	IA	IA	IA	IA
Drigg	2009/2010 Post-synergy	19.5	No Finds	No Finds	No Finds	No Finds	No Finds	No Finds
Drigg	2010/2011	30.4	<1	No Finds	No Finds	No Finds	No Finds	No Finds
Drigg	2011/2012	8.8	IA	IA	IA	IA	IA	IA
Drigg	2012/2013	10.8	No Finds	No Finds	No Finds	No Finds	No Finds	No Finds
Drigg	2013/2014	9.2	IA	IA	IA	IA	IA	IA
Drigg	2014/2015 Synergy 2	8.3	IA	IA	IA	IA	IA	IA
Drigg	2015/2016	1.1	IA	IA	IA	IA	IA	IA
Drigg	2016/2017	1.1	IA	IA	IA	IA	IA	IA

Notes: IA - Insufficient area coverage to estimate finds rates (<10 ha).

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